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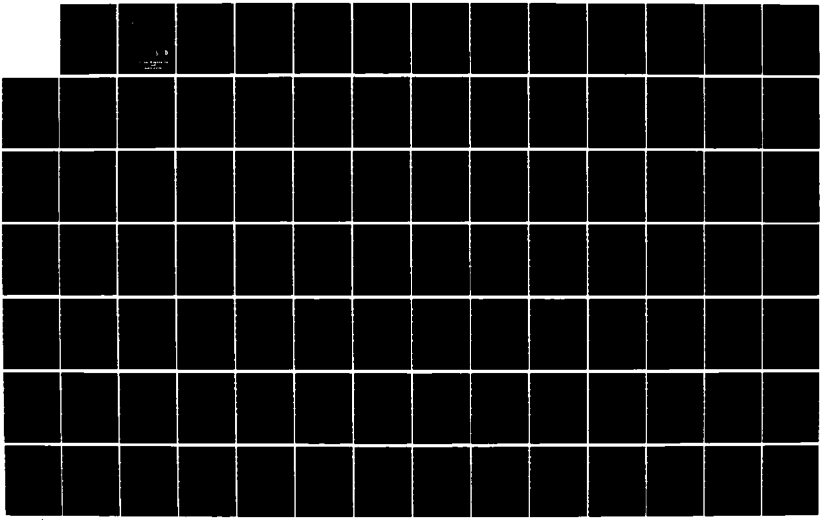

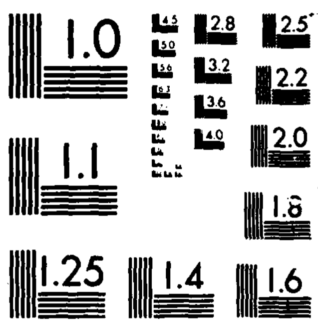

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DEEP SEA SHIP MOOR

USER'S MANUAL

SEADYN/DSSM

VOLUME 2

FPO-1-78 (16)

AUGUST 1978

Ocean Engineering and Construction

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This report documents the DESMOOR computer program which selects trial designs of mooring systems for surface ships in deep water. Either slack (negatively buoyant catenary) or taut (neutrally buoyant) moors can be treated. Given design coefficients for the mooring line material, the number and (Con't)

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headings of the mooring lines, and specifications of design constraints, the program selects the minimum require leg diameter. In the case of slack moors the anchor locations are also determined. A search is then made of defined component inventories to select buoys, anchors, chains, and hawsers as required by the design configuration. The program utilized the equations of static equilibrium at a reference point on the ship and the ship is presumed to be a rigid body with zero heave, pitch and roll. The external loadings on the ship are obtained from user-supplied wind and current load tables or approximate analytical functions. Similarity scaling is used when the load tables from one ship (or model) are used to approximate the loads on another. The DESMOOR program was developed as a preliminary design tool to be used in conjunction with the deep sea ship mooring static and dynamic analysis features of the SEADYN computer program.

USER'S MANUAL

SEADYN/DSSM

GENERAL PURPOSE CABLE AND DEEP SEA SHIP MOOR ANALYSIS COMPUTER PROGRAM

by

R. L. WEBSTER

NOVEMBER 1976
REVISED JULY 1978
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ABSTRACT

The basic theory and input instructions for a general purpose nonlinear analysis program for underwater cable and truss structures is described. A combination of the finite element and lumped parameter methods is used. Options are provided for the treatment of mooring systems for surface ships. The SEADYN/DSSM computer program treats nonlinearities arising from large displacements, large strains, velocity-squared drag loading, position dependent loading, hyper-elastic materials and constraints on the surface and bottom of the fluid field. The structure may be partly in water and partly in air. Analysis options provide for iterative/incremental solutions for static and transient dynamic responses. In addition, natural frequencies and modes may be determined and response spectrum calculations can be made to estimate the response of mooring systems to surface waves including the effects of steady state approximations of the wave induced drift forces. A unique option to check the adequacy of lines, buoys, and anchors is also provided.

ADMINISTRATIVE INFORMATION

The SEADYN/DSSM computer program has been developed over the past three years under various activities supported by the Electronics Systems Division of the General Electric Company, the United States Navy and the private efforts of the author as part of his Doctoral program at Cornell University. The recent improvements in the program, the generalization to treat ship's moorings and the production of this manual were supported by the Naval Facilities Engineering Command through contract number N62477-76-C-0002. This report is a combined user's manual which meets the requirements of Items (10) and (13) of the Milestones and Deliverable Schedule dated 17 June 1975 as revised 4 August 1975.

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1.0 INTRODUCTION

This report provides the basic information required to use the SEADYN/DSSM digital computer program. The analytical capability described herein is considered by the author to be the most advanced available for approximate analysis of cable structures and mooring systems using discrete element modeling techniques. Advanced state-of-the-art methods have been employed in all of the major aspects of the program. Capability is provided for the static and dynamic analysis of cable and mooring systems in which all of the major nonlinearities have been given consideration. Emphasis has been placed on versatility and generality.

The SEADYN program has developed through various stages since the summer of 1974. The starting point was a computer program known as NLIN[1] which was developed by the Bechtel Corporation in 1973 under contract to the Electronic Systems Division of the General Electric Company, Syracuse, NY. The NLIN program began with an unpublished cable finite element program written by Dr. John Leonard of the Illinois Institute of Technology in Chicago, Ill. The NLIN effort added fluid loading effects but retained the linearized incremental solution procedure. This author was technical advisor on that effort.

Noting that various deficiencies existed in the NLIN formulation, an effort was launched to study the general underwater structural response of cable systems. This effort eventually led to the doctoral thesis contained in Reference 2 and the SEADYN computer program. The theoretical work and program development was supported by the author's own activities and by various work assignments at GE. By the fall of 1975 the SEADYN program had the capability of dealing with general cable/truss systems using incremental, iterative and generalized iterative/incremental solution methods. Both the static and time domain dynamic analysis options were available. The discrete equations were derived using finite element theory, and the program had a single element in its library (the 3-D nonlinear truss element otherwise known as the 1-D simplex element in 3-D space [3]). In addition, lumped bodies representing buoys and anchors could be located at each node of the system. The program was written with fixed dimensions which limited it to problems with no more than 30 nodes and 100 elements.

In the development of SEADYN it was assumed that the cable system could be completely submerged in a fluid such as sea water and that imposed loads would include hydrodynamic effects from the relative velocity between an arbitrary flow field and the cable motion. Point loads could also be imposed at any node. Constraints were provided which could prevent nodes from moving out of the region between the fluid surface and the bottom.

In the fall of 1975, with funding from the Naval Facilities Engineering Command, an effort was begun which led to significant generalization of the SEADYN program. The main thrust of this effort was to develop an effective tool for analyzing the dynamic response of deep sea ship's moors. A surface ship and surface buoy modeling capability was added to SEADYN which allows the treatment of static response of complex moors to winds, surface and subsurface currents, and various working loads. A frequency domain dynamic response solution option was added which allows estimates of the regular wave and spectral responses to surface waves. The frequency domain solution uses ship response characteristics from a file generated external to the program (e.g., the NSRDC Ship Motion Program [4]) and also adjusts the static reference state to represent the effects of the steady-state portion of the second order wave-induced drift forces. In addition, the dimension restrictions were removed from the number of nodes and elements and various improvements were made in the solution routines. The work also developed a unique checking option which allows the user to evaluate the adequacy of the cable or mooring system.

This report gives a brief summary of the technical developments supporting the SEADYN/DSSM program, describes the solution procedures used, and details the input requirements. Following a description of the program output and error returns, a few sample problems are presented to demonstrate the versatility of the program. Details of the program structure are given in the programmer's reference manual [5] and specific applications of the program to the deep sea moor problem are given in Reference 6.

2.0 PROGRAM DESCRIPTION

2.1 OUTLINE OF THEORY

2.1.1 Basic Modeling Assumptions

The approach taken in the SEADYN/DSSM computer program to model cable and mooring systems can be described as a discrete element approach. It can be considered as a combination of the finite element method and the lumped parameter method.

In its classical form, the finite element method seeks to represent continuous physical systems with a set of discrete or finite elements which are formulated by assuming the character of the element response in terms of a set of interpolating functions. In its usual form it is equivalent to a Galerkin form of the method of weighted residuals where the weighting functions are defined individually on each element. Viewed from another perspective, the finite element method is a form of the Rayleigh-Ritz method in which the trial functions are defined only on individual subregions (elements) of the system. The basic equations for cables, mooring lines and hawsers are obtained using a simple finite element in the form of a straight line. The element is assumed to be straight both before and after deformation of the system, but no restriction is placed on the amount of stretch and/or rotation the element is subjected to. It is further assumed that bending and torsional effects are negligible. In the case of bending this means that the bending stiffness of the cable has negligible influence on the global response of the system. Neglect of the torsional effects does not mean that twist is unimportant. It simply means that coupling between twist and extension is assumed to have little effect on the overall shape and response of the system. An obvious situation where this is an invalid assumption is in low tension conditions where a twist instability may result in kinking or hockling.

The only deformable components in the system are assumed to be the cable elements. The material is assumed to be hyperelastic, i.e., nonlinear, time-independent with loading and unloading curves coincident. With the exception of the frequency domain solutions, internal damping effects are ignored.

Any component of the system which cannot be modeled as an individual line element or a set of line elements is assumed to be a rigid body. These rigid components are assumed to be lumped at a single point in the system. They may be assumed to have only a point effect or to act as a rigid connector for arbitrarily placed lines (e.g., a ship).

The system may be totally immersed in a fluid, suspended between two fluids (e.g., water and air) or fluid effects may be ignored. The treatment of fluid effects makes the fundamental assumption that the fluid and structure problems are uncoupled. This means that except for specific localized effects the overall fluid field characteristics are unaltered by the presence of the structure. Thus such things as flow alteration due to structural movement and blockage effects are not dealt with. More specifics on the assumptions and limitations of the fluid interaction with the structural system are discussed in Section 2.1.7 and Reference 2.

The Lagrangian approach is taken in describing the motion of the system. In this approach all physical variables are expressed in terms of their values at an initial reference state. It is possible to change the reference state by employing generalized coordinate transformations which account for distortions and rotations. Analytical procedures which begin from a reference state and never change that reference are called total Lagrangian. Updated Lagrangian is an obvious title for methods which periodically move or update the reference state. Either procedure can be used and the results obtained should be equivalent. In the developments which follow the configuration of a system (or an element) is designated by the capital letter C and a pre-superscript. The symbol ${}^{R}C$ means the reference configuration while ${}^{t}C$ means the configuration at some time, t. The definition of quantities like stress, strain and displacement usually involve two configurations. A pre-subscript is used to denote the reference configuration for such cases. Thus ${}^{t}_{o}U$ means a quantity in ${}^{t}C$ measured relative to ${}^{o}C$.

Details of the finite element method applicable to cable systems are given in Reference 2. Only brief summaries of the results pertinent to the SEADYN/DSSM program are given here.

2.1.2 The One-Dimensional Simplex Element

A finite element which has the form of a line (i.e., one-dimensional) and uses only the field parameters at the two ends of the line in the interpolating functions is referred to as a one-dimensional simplex element [3]. When the element is a straight line in 3D space and the field parameters are the nodal (end point) displacements the element is called a truss element in structural terminology.

Consider a single straight element which is defined by the position of two nodes (one at each end). Select a local coordinate system with the x axis extending from the first node to the second. The other two axes may be chosen arbitrary under the restriction that they form a right handed cartesian reference frame. When the element is in its unloaded state it has a length ${}^{0}L$. Assume the material constitutive relation has the form

$$ {}^{t}_{o}S = {}^{t}_{o}E \; {}^{t}_{o}\varepsilon \tag{2-1} $$

where

${}^{t}_{o}S$ is the 2nd Piola-Kirchhoff stress in ${}^{t}C$

${}^{t}_{o}\varepsilon$ is the Green's strain in ${}^{t}C$

${}^{t}_{o}E$ is a nonlinear material modulus which may be a function of strain.

The incremental form of this constitutive relation can be written for a small strain increment, $\Delta{}^{t}_{o}\varepsilon$.

$$ {}^{t+\Delta t}_{o}S = {}^{t}_{o}S + {}^{t}_{o}E_T \; \Delta{}^{t}_{o}\varepsilon \tag{2-2} $$

where ${}^{t}_{o}E_T$ is the tangent modulus evaluated at ${}^{t}C$.

Making the finite element assumption that the displacement at any position along the element is a linear function of the displacements of the nodes one can write

$$\{u\} = \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = \left[\left(1 - \frac{x}{R_L}\right) I_3 \;\vdots\; \frac{x}{R_L} \quad I_3 \right] \begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ u_2 \\ v_2 \\ w_2 \end{Bmatrix} \tag{2-3}$$

$$= {}_R[N]\ \{q\}$$

where

$\{u\}$ represents the components of the displacement from ${}^RC$

$\{q\}$ represents the components of the nodal displacements

${}_R[N]$ is called a shape function matrix

I_3 is the identity matrix of order 3

The symbolic expression for the large displacement kinematic relations (Green's Strain) for a movement from ${}^RC$ to ${}^tC$ can be written [2]

$${}^t_R\{\varepsilon\} = {}^t_R[D]\ {}^t_R\{u\} \tag{2-4}$$

Substitution from equation (2-3) yields

$${}^t_R\{\varepsilon\} = {}^t_R[D]\ {}_R[N]\ {}^t_R\{q\} = {}^t_R[B]\ {}^t_R\{q\} \tag{2-5}$$

The general form of the equations of motion for the element can be written

$${}^t_R[M]\ {}^t_R\{\ddot{q}\} = {}^t\{f\} - {}^t\{g\} = {}^t\{R\} \tag{2-6}$$

where

$^{t}_{R}[M]$ is the element mass matrix

$^{t}\{f\}$ represents the external nodal forces in ^{t}C

$^{t}\{g\}$ represents the nodal reactions in ^{t}C

$^{t}\{R\}$ is called the force residual

The mass matrix for the straight element can be written in two forms:

Consistent Mass Matrix

$$[M] = \frac{^{R}\rho \; ^{R}A \; ^{R}L}{3} \begin{bmatrix} I_3 & \frac{1}{2} I_3 \\ \frac{1}{2} I_3 & I_3 \end{bmatrix} \tag{2-7}$$

Lumped Mass Matrix

$$[M] = \frac{^{R}\rho \; ^{R}A \; ^{R}L}{2} \begin{bmatrix} I_3 & 0 \\ 0 & I_3 \end{bmatrix} \tag{2-8}$$

where $^{R}\rho$ is the element material density in ^{R}C, and ^{R}A is the element cross-sectional area in ^{R}C. With the assumption of conversation of mass, the element mass matrix does not change with deformation. The pre-sub and superscripts are used in equation (2-6) since this is not true of fluid added mass.

The consistent mass matrix is obtained from the kinetic energy and equation (2-3). The lumped form can be obtained by the intuitive process of lumping half of the element mass at each node or by summing all the terms on each row of the consistent mass matrix and assigning the sum to the diagonal position.

The external forces may be due to point or distributed loads. Point loads appear as specific entries in the global equations (see Section 2.1.7). Distributed loads are usually from gravity effects and/or fluid loading. Fluid loading effects are discussed in Section 2.1.4. The general form of the gravity loading is

$$ {}^{t}\{f\} = \int_{0}^{{}^{R}L} {}^{R}[N]^{T}\, {}^{R}\{\gamma\}\, dx \tag{2-9} $$

where

${}^{R}\{\gamma\}$ represents the components of the element specific weight (in fluid) relative to the local coordinate system

${}^{R}[N]^{T}$ is the transpose of ${}^{R}[N]$

Substitution from equation (2-3) into equation (2-9) and noting the orientation of the element with respect to the direction of gravity leads to the conclusion that these forces are equivalent to placing one half of the element weight acting in the gravity direction at each node. It should be noted that equation (2-9) assumes mass is conserved.

The internal forces of equation (2-6) can be written [2]

$$ {}^{t}\{g\} = {}^{t}_{R}S\ {}^{R}A\ \frac{{}^{t}L}{{}^{R}L}\ \{\frac{-\lambda}{\lambda}\} \tag{2-10} $$

where $\{\lambda\}$ is a unit vector in the direction of the deformed element. The stress term, ${}^{t}_{R}S$, can be written

$$ {}^{t}_{R}S = \frac{{}^{t}P}{{}^{R}A}\ \frac{{}^{R}L}{{}^{t}L} \tag{2-11} $$

where ${}^{t}P$ is the element load in the deformed state. This allows the force residual to be written

$$ {}^{t}\{R\} = {}^{t}\{f\} - {}^{t}P\ \{\frac{-\lambda}{\lambda}\} \tag{2-12} $$

An incremental form of the motion equations can be written

$$ {}^{t}_{R}[M]\ \{\Delta\ddot{q}\} = \{\Delta f\} - {}^{t}_{R}[K_T]\ \{\Delta q\} - {}^{t}_{R}[C]\ \{\Delta\dot{q}\} \tag{2-13} $$

where

$$\{\Delta q\} = {}^{t+\Delta t}_{R}\{q\} - {}^{t}_{R}\{q\} \tag{2-14}$$

and

${}^{t}_{R}[K_T]$ is called the tangent stiffness matrix

${}^{t}_{R}[C]$ is an incremental damping matrix

The stiffness matrix can be obtained from consideration of the second variation of the strain energy in ${}^{t}C$. The result is [2]

$$ {}^{t}_{R}[K_T] = {}^{t}_{R}\left(\begin{bmatrix} k_o & -k_o \\ -k_o & k_o \end{bmatrix} + \begin{bmatrix} k_1 & -k_1 \\ -k_1 & k_1 \end{bmatrix} + \begin{bmatrix} k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} + \begin{bmatrix} k_G & -k_G \\ -k_G & k_G \end{bmatrix} \right) \tag{2-15}$$

where

$$[k_o] = \frac{{}^{t}_{o}E_T \; {}^{o}A}{{}^{o}L} \left(\frac{{}^{R}L}{{}^{o}L}\right)^2 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$[k_1] = \frac{{}^{t}_{o}E_T \; {}^{o}A}{{}^{o}L} \left(\frac{{}^{R}L}{{}^{o}L}\right)^2 \begin{bmatrix} 2 & \theta_1 & \theta_2 & \theta_3 \\ & \theta_2 & 0 & 0 \\ & \theta_3 & 0 & 0 \end{bmatrix}$$

$$[k_2] = \frac{{}^{t}_{o}E_T \; {}^{o}A}{{}^{o}L} \left(\frac{{}^{R}L}{{}^{o}L}\right)^2 \begin{Bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{Bmatrix} \begin{Bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{Bmatrix}^T$$

$$[k_G] = \frac{{}^{t}P}{{}^{t}L} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\theta_1 = \frac{{}^t_R u_2 - {}^t_R u_1}{R_L}$$

$$\theta_2 = \frac{{}^t_R v_2 - {}^t_R v_1}{R_1}$$

$$\theta_3 = \frac{{}^t_R w_2 - {}^t_R w_1}{R_L}$$

In many situations (e.g., fluid loading) the force is dependent on the deflection. In this case

$$\{\Delta f\} = \frac{\partial\ {}^t\{f\}}{\partial\ t}\ \Delta t + \frac{\partial\ {}^t\{f\}}{\partial\ {}^t_R\{q\}}\ \{\Delta q\}$$

$$= \{\Delta\overline{f}\} + {}^t_R[K_R]\ \{\Delta q\} \qquad (2\text{-}16)$$

The incremental motion equations are then written

$${}^t_R[M]\ \{\Delta\ddot{q}\} + {}^t_R[C]\ \{\Delta\dot{q}\} + {}^t_R[\overline{K}_T]\ \{\Delta q\} = \{\Delta\overline{f}\} \qquad (2\text{-}17)$$

where

$${}^t_R[\overline{K}_T] = {}^t_R[K_T] - {}^t_R[K_R] \qquad (2\text{-}18)$$

Equation (2-13) or (2-18) can be used to model small displacement response about a steady state deformed configuration, or it can be used in nonlinear dynamics by recalculating the stiffness matrix at each step. It should be noted that both equations neglect the position dependent effects in the mass matrix. The incremental load rotation matrix, $[K_R]$, is nonsymmetric and causes some problems in applying equation (2-18). Its effect when small increments are used is felt to be minimal and is ignored in SEADYN/DSSM. The incremental damping matrix may be difficult to obtain in the more general situations. A simplified treatment is discussed in Section 2.2.3.

An alternative form of the incremental equations is obtained from equation (2-6) by expanding only the internal loads in a Taylor series and neglecting higher order terms. The result is

$$ {}^{t+\Delta t}_{R}[M]\ {}^{t+\Delta t}_{R}\{\ddot{q}\} + {}^{t}_{R}[K_T]\ \{\Delta q\} = {}^{t+\Delta t}\{f\} - {}^{t}\{g\} \qquad (2\text{-}19) $$

This equation is linearized by approximating ${}^{t+\Delta t}\{f\}$ and ${}^{t+\Delta t}_{R}[M]$ with their values at $t+\Delta t$ while remaining in the orientation defined by ${}^{t}_{t}C$. Any damping effects are assumed to be included in ${}^{t+\Delta t}\{f\}$.

2.1.3 Lumped Bodies

Two forms of lumped bodies are considered. The simplest form treats the body as a single point with three displacement degrees of freedom. The point is assumed to have mass but no rotational inertia. No elasticity effects are attributed to the body, but it may be a means of inducing fluid loads into the system (see Section 2.1.4). If the mass of the body is m, then the mass matrix is simply

$$ [M]_{lump} = m \begin{bmatrix} 1 & & \\ & 1 & \\ & & 1 \end{bmatrix} \qquad (2\text{-}20) $$

This body affects only one node in the system.

The second form is that of a rigid body with spatial dimensions. The mass is still assumed to be concentrated at a single point but that point has six degrees of freedom. The mass matrix assumed for this case has specific forms only in the case of mooring buoys and surface ships. The program generates the mass matrix for mooring buoys and assumes the mass matrix is defined by input from the ship's motion file for surface ships. See Sections 2.1.8 and 2.1.9 for details. In either case the mass matrix is a 6 x 6 matrix.

2.1.4 Modeling Fluid Loads

The primary assumption regarding the effect of fluid immersion on the cable system as stated in Section 2.1.1 is that the fluid and structural problems are uncoupled. The independence principle [7] is assumed in the treatment of

fluid loading on the cables. In brief, the independence principle asserts that the fluid loading can be treated as resulting from two separate flows: one normal and one tangential to the cable.

The fluid induced loads can be separated into a part involving the relative velocity between the cable and the fluid and a part involving the relative acceleration. The velocity related terms can be written

$$\{w\} = w_N \{\eta\} + w_T \{\bar{\lambda}\} \tag{2-21}$$

where

$$w_N = 1/2\ \rho_f\ C_N\ D\ V_N^2 \tag{2-22}$$

$$w_T = 1/2\ \rho_f\ C_T\ D\ V_T^2 \tag{2-23}$$

$\{\eta\}$, $\{\bar{\lambda}\}$ are unit vectors in the directions of the normal and tangential components of the relative velocity

C_N, C_T are normal and tangential drag coefficients

D is the drag diameter of the cable

ρ_f is the density of the fluid

The fluid loading vector for an element is then

$$^t\{f\} = \int_0^{^tL} {}^t[N]^T \{w\}\ dL \tag{2-24}$$

with {w} approximated as constant over the length this reduces to the usual lumping procedure of placing one half of the load at each node.

The acceleration related portion of the fluid loading can be separated into a part due to flow field acceleration and a part due to structural acceleration. The flow field acceleration part is neglected in the cable loading and the structural acceleration part is treated as an added mass. The added mass matrix for a straight element can be written

$$[M_{added}] = \frac{C_M \, \rho_f \, {}^{R}A \, {}^{R}L}{2} \begin{bmatrix} 0 & & & & & \\ & 1 & & & & \\ & & 1 & & & \\ & & & 0 & & \\ & & & & 1 & \\ & & & & & 1 \end{bmatrix} \tag{2-25}$$

where

C_M is an added mass coefficient.

It should be noted that there is no added mass tangential to the cable which makes this a position dependent term.

In some of the solution procedures economies can be achieved if the mass matrix is diagonal. A lumped form of the combined cable and fluid added mass matrix can be written:

$$[M] = \frac{\bar{\rho} \, {}^{R}A \, {}^{R}L}{2} \, [I_6] - \frac{C_M \, \rho_f \, {}^{R}A \, {}^{R}L}{2} \begin{bmatrix} 1 & & & & & \\ & 0 & & & & \\ & & 0 & & & \\ & & & 1 & & \\ & & & & 0 & \\ & & & & & 0 \end{bmatrix} \tag{2-26}$$

$$= [M_o] + [M_{NL}]$$

where

$$\bar{\rho} = {}^{R}\rho + C_M \, \rho_f \tag{2-27}$$

This form still presents some difficulties which will be dealt with in the discussion of the solution procedures.

Fluid loads on submerged lumped bodies are estimated using an approach similar to that used for the cable element. Two forms for lumped bodies are considered: spherical and an end-faired cylinder. The drag loading on a sphere is given by

$${}^{t}\{f_{sphere}\} = 1/2 \, \rho_f \, C_D \, D \, V^2 \;\; {}^{t}\{\lambda\} \tag{2-28}$$

where

- D is the diameter of the sphere
- C_D is the drag coefficient
- V is the relative velocity between the fluid and the point where the sphere is located.
- ${}^{t}\{\lambda\}$ is a unit vector in the direction of relative velocity.

The added mass for a sphere is

$$[M_{added}] = \frac{C_M \rho_f \pi D^3}{6} [I_3] \qquad (2\text{-}29)$$

The end faired cylinder loading and added mass is assumed to have the same form as that for a cable element except that the total effect is placed at a single point rather than being distribured between two nodes.

There are specific fluid effects peculiar to surface buoys and ships which are discussed in Sections 2.1.8 and 2.1.9.

2.1.5 Coordinate Systems and Transformations

Equations for the cable element, as well as ships and mooring buoys, are most readily developed in a local or intrinsic coordinate system which is considered to move with the element. The development of a global set of equations which represents the behavior of the assembled system of elements requires a single global coordinate system. Transformations between the local coordinate system and the global system in a reference configuration are accomplished by the usual rotation of coordinates. The general form for the components of a vector at a point is

$${}^{t}_{R}\{u\}_{local} = {}_{R}[\hat{T}]\ {}^{t}_{R}\{u\}_{global} \qquad (2\text{-}30)$$

Columns of the transformation matrix are the components of a unit vector in the direction of the local coordinate axis expressed in the global system. Since only right-handed cartesian coordinates are considered, the inverse transformation is obtained with the transpose of ${}_{R}[\hat{T}]$. All contributions from the external and internal loads, etc., must be transformed to the global system before they are combined with other components in the system.

It should be noted that these coordinate transformations apply only to quantities expressed relative to a specific reference configuration. As long as the reference configuration remains fixed the individual coordinate transformations remain unchanged regardless of how much deformation occurs between ${}^{R}C$ and ${}^{t}C$.

Coordinate transformations involving nodal point displacements for an element can be written

$$ {}^{t}_{R}\{q\}_{local} = {}_{R}\begin{bmatrix} \hat{T} & \\ & \hat{T} \end{bmatrix} {}^{t}_{R}\{q\}_{global} = {}_{R}[T] \quad {}^{t}_{R}\{q\}_{global} \tag{2-31} $$

The form for nodal forces is similar. When one transforms the incremental motion equations from the local to the global system the equations take the form

$$ {}^{t}_{R}[\overline{M}]\ \{\Delta\ddot{q}\}_{global} + {}^{t}_{R}[\overline{C}]\ \{\Delta\dot{q}\}_{global} + {}^{t}_{R}[\overline{K}_{T}]\ \{\Delta q\}_{global} = \{\Delta f\}_{global} \tag{2-32} $$

where

$$ {}^{t}_{R}[\overline{M}] = {}_{R}[T]^{T}\ {}^{t}_{R}[M]\ {}_{R}[T] $$

$$ {}^{t}_{R}[\overline{C}] = {}_{R}[T]^{T}\ {}^{t}_{R}[C]\ {}_{R}[T] $$

$$ {}^{t}_{R}[\overline{K}_{T}] = {}_{R}[T]^{T}\ {}^{t}_{R}[K_{T}]\ {}_{R}[T] $$

$$ \{\Delta f\}_{global} = {}_{R}[T]^{T}\ \{\Delta f\}_{local} $$

Thus it is seen that coordinate rotations do not alter the form of the equations. Unless specific emphasis is required, no further distinction between the local and global equation forms will be made. It is assumed that the equations are written in a homogeneous system, i.e., all displacements, forces, stiffnesses, etc., are in the same coordinate system.

2.1.6 Slave/Master Transformations

The generalized rigid bodies used to model ships and mooring buoys require some special manipulations to connect them to the rest of the system. Their motions are assumed to be described by the six degrees of freedom of a single point. The attachments, however, will not connect to the rigid body at that node. Since the body is assumed to be rigid, it is possible to express the

motion of any point on the body in terms of the motion of a single point and the relative positions on the body. The node used to model the body is called a master node. Any other point on the body is called a slave node. Given the six components of motion at the master node, the translation components of a slave node can be written:

$$\{q\}_{slave} = \left[\begin{array}{ccc:ccc} 1 & 0 & 0 & 0 & \Delta z & -\Delta y \\ 0 & 1 & 0 & -\Delta z & 0 & \Delta x \\ 0 & 0 & 1 & \Delta y & -\Delta x & 0 \end{array}\right] \begin{Bmatrix} \{q\} \\ \cdots \\ \{\theta\} \end{Bmatrix}_{master} \qquad (2\text{-}23)$$

OR

$$\{q\}_{slave} = [\hat{T}_{SM}] \, \{q\}_{master}$$

where Δx, Δy, Δz are components of the distance between the two points measured from the master to the slave, i.e., $\Delta x = x_{slave} - x_{master}$, etc. The matrix $[\hat{T}_{SM}]$ can be viewed as a generalized form of the coordinate transformation represented by equation (2-30) and the transformation procedures of the previous section can be employed.

It should be noted that the slave/master transformation involves an alteration of the number of degrees of freedom. When an end of a cable element connects to a slave node, the application of equation (2-33) in the transformation indicated by equation (2-32) results in a stiffness matrix (etc.) which is 9 x 9 instead of 6 x 6. It should further be noted that the slave/master transformation form assumes small displacements and is therefore only applicable to the incremental equations.

Calculations of the position of a slave node once an estimate of the position of the master node is obtained is more appropriately made using the general coordinate transformation rather than employing equation (2-33). The form is

$$^{t}\{x\}_{slave} = {}^{t}\{x\}_{master} + {}^{t}_{R}[\hat{T}] \left({}^{R}\{x\}_{slave} - {}^{R}\{x\}_{master} \right) \qquad (2\text{-}34)$$

where ${}^{t}_{R}[\hat{T}]$ is a rotation matrix of the form (2-30) which represents the total angle changes from ${}^{R}C$ to ${}^{t}C$ at the master node.

2.1.7 Global Equation Forms

The contributions from each of the elements in the system (cables, lumped bodies, and rigid bodies) can be combined in a very simple and direct manner once they have been generated and transformed to the global coordinate system. This is done element by element by accumulating the element contributions in the appropriate position of the global arrays. An ordering of the degrees of freedom is implied in this procedure. The order assumed in SEADYN/DSSM is simply the three displacement components (x,y,z) stored in the order of the node number. Thus the global nodal displacement vector assumes the x component of node number one is first, the y component of node z is fourth, etc. By requiring fixed (no movement) nodes and slave (movement defined in terms of another node) nodes to be numbered after nodes which have active degrees of freedom, the solution book-keeping is greatly simplified.

The assembled global equations have essentially the same form as the element motion equations. The main distinction is that the order of the equations is increased to include all of the active degrees of freedom in the system. Noting this the total nonlinear equations of motion can be written

$$ {}^{t}_{R}[M]\ {}^{R}_{t}\{\ddot{q}\} = {}^{t}\{f\} - {}^{t}\{g\} = {}^{t}\{R\} \tag{2-35} $$

The two incremental forms are

$$ {}^{t}_{R}[M]\ \{\Delta\ddot{q}\} + {}^{t}_{R}\ [C]\ \{\Delta\dot{q}\} + {}^{t}_{R}[\overline{K}_{T}]\ \{\Delta q\} = \{\Delta\overline{f}\} \tag{2-36} $$

$$ {}^{t+\Delta t}_{R}[M]\ {}^{t+\Delta t}_{R}\{q\} + {}^{t}_{R}[K_{T}]\ \{\Delta q\} = {}^{t+\Delta t}\{f\} - {}^{t}\{g\} \tag{2-37} $$

It should be emphasized that these represent the assembled equations for the system and that it is assumed that the constraints implied by the boundary conditions and slave/master conditions are accounted for. The dynamic equations reduce to the static equations when the time dependent terms are dropped. Thus the nonlinear static equation is

$$ {}^{t}\{R\} = 0 \tag{2-38} $$

and the incremental static equations are

$$ {}^{t}_{R}[\overline{K}_T]\ \{\Delta q\} = \{\Delta \overline{f}\} \tag{2-39}$$

$$ {}^{t}_{R}[K_T]\ \{\Delta q\} = {}^{t+\Delta t}\{f\} - {}^{t}\{g\} \tag{2-40}$$

In the static case the parameter t is used to signify a load step rather than a time step. The static equations presume a stable physical system has been described by imposing adequate constraints on the system. If this is not so, the stiffness matrices are singular and there is not a unique configuration of the system which will satisfy the equation. In the case of nonlinear systems (particularly those with surface ships and mooring buoys) the static global equations may be ill-conditioned. This means they are nearly singular and numerical errors in the solution procedure may lead to apparent singularities. This will be given more attention in Section 2.2.1.

In some situations one or more of the motion components at a node may be constrained, but since other components at the node remain active or the constraint is a function of the position it is not appropriate to list the node as a fixed one. In those cases an artificial stiffness can be added to the system which has the effect of constraining the degree of freedom. This is done by adding a large value to the diagonal element of the stiffness matrix at the position corresponding to the constrained degree of freedom.

2.1.8 Surface Ships

The rigid body element is used to model surface ships. A single node point is used to define the position of the ship. Since the node must express the angular as well as spatial position of the ship it is required to have six degrees of freedom. (The SEADYN/DSSM program uses two consecutive nodes of three degrees of freedom each to define a ship.) Attachments of mooring lines and/or working lines are handled through the slave/master transformation.

In static analyses the steady state effects of winds and surface currents acting on the ship are treated as lateral and longitudinal forces and a yaw moment which are assumed to act at the ship's reference point. The values of these forces depend on the flow velocities and the angle between the ship's heading and the flow direction. Empirical load tables giving load coefficients versus heading or analytical load functions may be used. The empirical approach is given in NAVFAC DM-26 [8] and both approaches were summarized in Reference 9. That presentation is repeated in Appendix B for the convenience of the user. The structure of a data file for ship loads is described in Appendix C.

The dynamic equations for the response of surface ships to waves are usually given in an incremental linearized form. These equations have the form

$$ {}^{t}_{t}[M_S + M_{AS}]\ \{\ddot{u}_S\} + {}^{t}_{t}[C_S]\ \{\dot{u}_S\} + {}^{t}_{t}[K_S]\ \{u_S\} = \{f_S\} \qquad (2\text{-}41) $$

where

$\{u_S\}$ represents the six components of ship's motion (surge, sway, heave, roll, pitch, yaw)

${}^{t}_{t}[M_S]$ is the ships mass matrix including rotational inertial terms

${}^{t}_{t}[M_{AS}]$ is the added mass due to fluid acceleration effects

${}^{t}_{t}[C_S]$ is an equivalent linearized damping matrix

${}^{t}_{t}[K_S]$ is the ship's hydrostatic restoring matrix

$\{f_S\}$ are the point equivalent forces representing the wave induced exciting forces

In order to obtain this linearization it is usually assumed that the ship is driven by a simple harmonic wave. With this assumption, the forces, added mass and damping are frequency and heading dependent. In addition, the linearization of the roll damping term makes it dependent on the magnitude of the roll angle. Equations of the form of (2-41) can be obtained for slender bodies using strip theory [4]. A more general theory is required for other

forms [10]. The SEADYN/DSSM program assumes the values for these coefficients are provided through a data file. The format of that data file is described in Appendix D.

The element equation represented by equation (2-41) can be manipulated as any other element equation and combined with the global equations of the system. No new concepts are involved in these operations.

2.1.9 Mooring Buoys

Ship's moors often involve surface buoys which support the mooring line and are connected to the ship through a hawser. This type of buoy usually remains on the surface where it is subjected to the effects of winds, currents and waves. The general form of the buoy motion equations linearized to represent small excursions from a static reference state can be written:

$$ {}^{t}_{t}[M_{SB}]\,\{\ddot{u}_{SB}\} + {}^{t}_{t}[C_{SB}]\,\{\dot{u}_{SB}\} + {}^{t}_{t}[K_{SB}]\,\{u_{SB}\} = \{f_{SB}\} \qquad (2\text{-}42) $$

where the various terms follow the previously established pattern. The forcing term represented by $\{f_{SB}\}$ deals only with wave excitation. Static load effects on a mooring buoy follow the same form as described previously in Section 2.1.3.

In order to avoid a great deal of complexity, it is assumed that the buoy is spherical in shape and that a local cartesian coordinate system is selected which is vertical in the z direction and has the incident wave traveling in the +x direction. No loss of generality is incurred with this choice of coordinate system on a spherical buoy since the character of the coefficients do not depend on the orientation or attitude of the buoy. The problem is further simplified if it is assumed that the buoy is homogeneous with the center of gravity at the geometric center of the buoy and that the geometric center is located at the water line in the reference state.

Attachements of hawser and mooring lines to the buoy can be readily handled if their positions relative to the local coordinate system are known. The

rigid link transformation of equation (2-33) is used for this purpose. The positions of the attachments can be found from the static solution.

Since it is assumed that the equations use ${}^{t}C$ as the reference configuration, the configuration notation will be dropped for this discussion.

Transformation from the local to the global system for assembly of the buoy equations with the rest of the moor system equations is a straightforward process which follows the method outlined previously. For this reason only the coefficients in the local coordinate system will be given here. It should be kept in mind that the following equations represent the incremental motion equations for a surface buoy in the local coordinate system just described.

Given that the buoy has a mass designated by m and a mass moment of inertia, J_m, the buoy portion of the mass matrix is

$$[M_B] = \begin{bmatrix} m\ I_3 & 0 \\ 0 & J_M\ I_3 \end{bmatrix} \tag{2-43}$$

where I_3 is the identity matrix of order 3. The assumption of a homogeneous sphere should be recalled at this point. If the attachments contribute significant mass, their effects can be treated by including additional lumped masses at those nodes.

The added mass has the form:

$$[M_A] = \begin{bmatrix} A_{xx} & 0 & 0 & 0 & A_{x\theta} & 0 \\ & A_{yy} & 0 & A_{y\phi} & 0 & 0 \\ & & A_{zz} & 0 & 0 & 0 \\ & \text{(SYM)} & & A_{\phi\phi} & 0 & 0 \\ & & & & A_{\theta\theta} & 0 \\ & & & & & A_{\psi\psi} \end{bmatrix} \tag{2-44}$$

The mass matrix is then given by

$$[M_{SB}] = [M_B] + [M_A] \tag{2-45}$$

The wave damping matrix has a form similar to the added mass matrix. Specific values for the added mass and damping coefficients for a sphere were given by Patton [11]. His values were obtained by curve fitting the analytical results presented by Kim [12]. The nondimensional values obtained were *

$$\begin{aligned} M_x &= 1.089 + 0.529\,a' && \text{for } 0 < a' < 0.74 \\ &= 1/(-0.0318 + 0.954\,a') && \text{for } 0.74 < a' < 3.4 \end{aligned} \tag{2-46}$$

$$\begin{aligned} M_z &= 1.85 && \text{for } 0 < a' < 0.1 \\ &= 1.02\,a'^{-0.256} && 0.1 < a' < 3.4 \end{aligned} \tag{2-47}$$

$$\begin{aligned} N_x &= 0 && \text{for } 0 < a' < 0.1 \\ &= -0.069 + 0.715\,a' && \text{for } 0.1 < a' < 1.37 \\ &= 1.595 && \text{for } 1.37 < a' < 3.4 \end{aligned} \tag{2-48}$$

$$\begin{aligned} N_z &= 0.126 + 1.7\,a' && \text{for } 0 < a' < 0.4 \\ &= 1.18\,e^{-0.83a'} && \text{for } 0.4 < a' < 3.4 \end{aligned} \tag{2-49}$$

where a' is the nondimensional frequency given by

$$a' = \frac{2\pi a}{\lambda} = \frac{a\ \omega^2}{g} \tag{2-50}$$

and

a = radius of sphere

λ = wavelength

ω = circular frequency of wave encounter

The added mass terms are nondimensionalized by the factor ρa^3 and the damping terms by the factor $\rho a^3 \omega$, thus

* See the Addendum at the end of this report for an alternative curve fitting which was used in the program.

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$$A_{xx} = A_{yy} = \rho a^3 M_x$$
$$A_{zz} = \rho a^3 M_z \qquad (2\text{-}51)$$

$$C_{xx} = C_{yy} = \rho a^3 \omega N_x$$
$$C_{zz} = \rho a^3 \omega N_z \qquad (2\text{-}52)$$

The roll, pitch and yaw added mass terms arise from fluid viscosity and they can be written

$$A_{\phi\phi} = A_{\theta\theta} = A_{\psi\psi} = \frac{4\pi\,\rho a^5}{3} \quad \frac{1 + \beta a}{1 + 2\beta a + 2\beta^2 a^2} \qquad (2\text{-}53)$$

where

$$\beta = \sqrt{\frac{\omega}{2\nu}} \qquad (2\text{-}54)$$

and ν = the kinematic viscosity of the fluid. Since the kinematic viscosity of water is of the order of 10^{-5} ft^2/sec, the rotational added mass terms will be small compared to the buoy inertia terms. Damping due to rotational motion is very small and will be neglected. Thus,

$$C_{\phi\phi} = C_{\theta\theta} = C_{\psi\psi} = 0 \qquad (2\text{-}55)$$

When the center of pressure does not coincide with the center of gravity of the buoy, a coupling between lateral and rotational motions exists. These terms can be written:

$$A_{x\theta} = A_{xx}\,(z_{cg} - z_{cp})$$
$$A_{y\phi} = -A_{yy}\,(z_{cg} - z_{cp}) \qquad (2\text{-}56)$$

$$C_{x\theta} = C_{xx}\,(z_{cg} - z_{cp})$$
$$C_{y\phi} = -C_{yy}\,(z_{cg} - z_{cp}) \qquad (2\text{-}57)$$

With the origin of the local coordinate system at the geometric center (also center of gravity), z_{cg} is zero. The center of pressure for a half submerged sphere is obtained from

$$z_{cp} = \frac{\int_S z\, n_x\, dS}{\int_S n_x\, dS} = \frac{\int_0^{-a} z \sqrt{a^2 - z^2}\, dz}{\int_0^{-a} \sqrt{a^2 - z^2}\, dz} = \frac{4a}{3\pi} \tag{2-58}$$

The damping terms presented above do not represent the effects of viscous drag. The viscous terms involve the square of the relative velocity between the buoy and the fluid and are therefore nonlinear. The viscous effects are generally of less importance than the wave damping. Obviously, this is not the case for the rotational movement since those terms are zero for wave damping. In a free-floating buoy the viscous rotational terms would play an important part, but in a mooring system where the hawser and mooring leg restrain the buoy the rotation is limited. Therefore, all of the viscous terms will be neglected rather than attempting to linearize them.

The only nonzero hydrostatic restoring force on a half-submerged spherical buoy acts in the heave direction. Its value for small displacements is

$$K_{zz} = \pi a^2 \rho g \tag{2-59}$$

When the buoy provides a connection between a mooring line and a hawser it develops an additional stiffness (resistance to motion) due to the tensile force being transmitted across it. This is analogous to the geometric stiffness term, $[K_G]$, seen in the cable element stiffness matrix in Section 2.1.2. This geometric stiffness effect is automatically taken into account by the rigid link transformation of the elements representing the attached lines.

The right-hand side of equation (2-42) represents the forces due to surface waves. Assuming the wave is harmonic in form, Kim [13] shows that the wave induced forces can be written

$$\{f_{SB}\} = \begin{Bmatrix} A^S_{xx}\ \ddot{X}_w + C^S_{xx}\ \dot{X}_w \\ 0 \\ A^S_{zz}\ \ddot{Z}_w + C^S_{zz}\ \dot{Z}_w + I_1\ Z_w \\ 0 \\ A^S_{\theta\theta}\ \ddot{\theta}_w + C^S_{\theta\theta}\ \dot{\theta}_w + I_2\ \theta_w \\ 0 \end{Bmatrix} \tag{2-60}$$

where

$$A^S_{xx} = \rho a^3\ M^S_x \tag{2-61}$$

$$C^S_{xx} = \rho a^3\ \omega\ N^S_x \tag{2-62}$$

$$I_1 = \rho g \int_S e^{a'(z+ix)}\ n_z\ ds \approx \rho g \int_S \cos\ (a'x)\ n_z\ ds \tag{2-63}$$

$$I_2 = \rho g \int_S e^{a'(z+ix)}(xn_z - zn_x)\ ds \tag{2-64}$$

For the half submerged sphere

$$A^S_{\theta\theta} = C^S_{\theta\theta} = I_2 = 0 \tag{2-65}$$

The wave pressure component of the heave exciting force, I_1, is closely approximated by the pressure at the water surface distributed over the cross-section at the water surface. A plot of this function versus the nondimensional frequency is given in Figure 2-1.

The values for M^S_x, M^S_z, N^S_x and N^S_z for a half submerged sphere were given by Kim [13]. A polynomial curve fit of those functions plus the curve for I_1 are summarized in the following table.

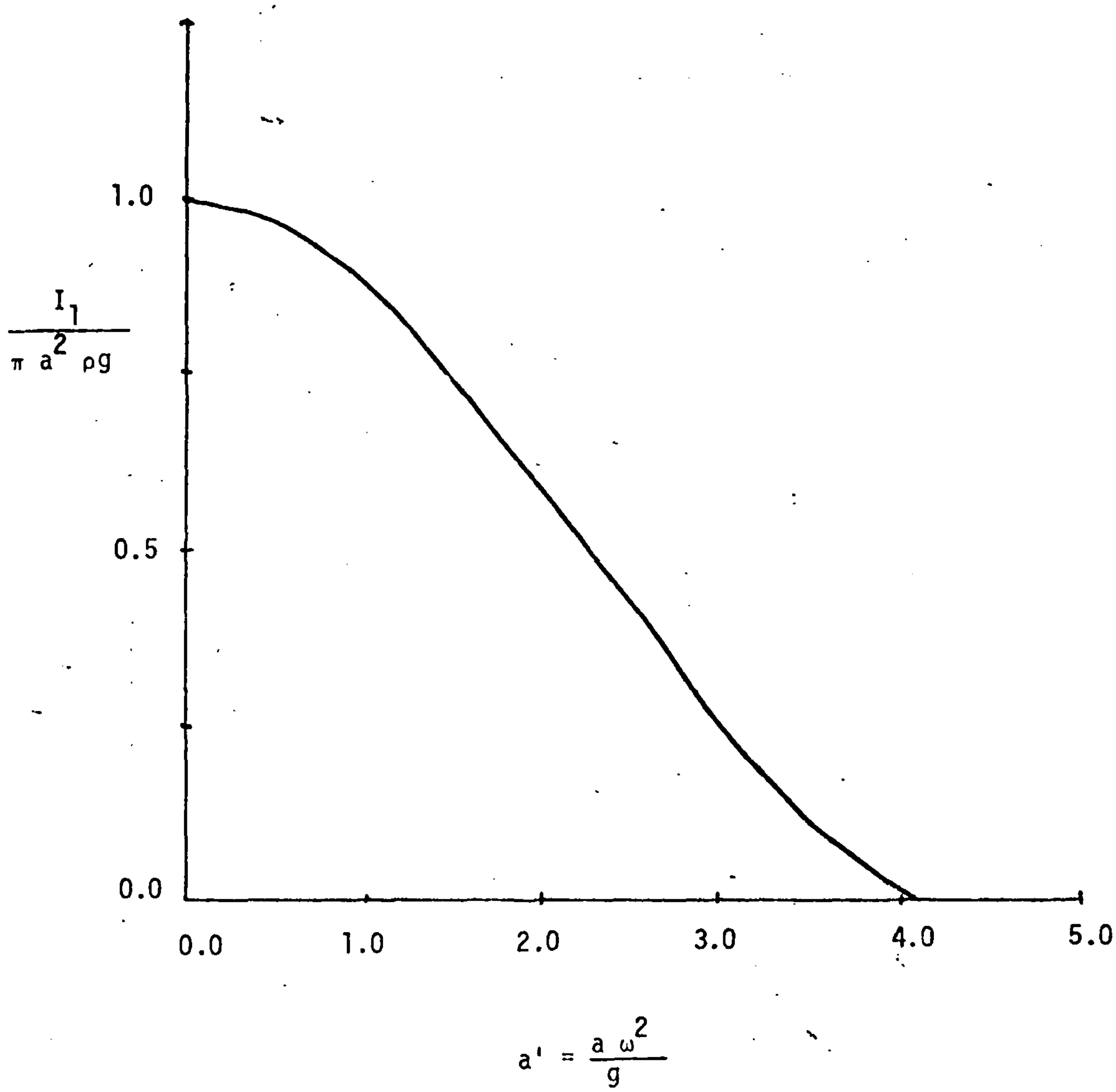


FIGURE 2-1 HEAVE EXCITING FORCE FOR HALF-SUBMERGED SPHERE

SUMMARY OF WAVE EXCITING FORCE COEFFICIENTS

FUNCTION	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7
M_x^S	0.	1.7586	-8.2171	12.0253	-8.2882	3.0081	-0.5576	0.0416
M_z^S	1.7868	1.0552	-10.5792	17.2729	-13.2596	5.3272	-1.0781	0.0866
N_x^S	1.0833	0.0833	-1.4496	0.7753	-0.0705	-0.0314	0.0055	0.
N_z^S	0.	4.2382	-8.5367	8.2743	-4.6849	1.5633	-0.2823	0.0211
$I_1/\pi a^2 \rho g$	1.0	-0.0004	-0.1218	-0.0026	0.0069	-0.0007	0.	0.

where the function form is:

$$F = \sum_{i=0}^{N} a_i (a')^i \tag{2-66}$$

Thus all of the terms necessary for treating the small displacement behavior of a restrained, half-submerged spherical buoy are available. The assumptions employed appear to be reasonable and should lead to a good approximation of the buoy effects in a deep sea moor. Although a spherical buoy has been assumed, a comparison of the curves presented by Kim [12] for a sphere and those presented by Garrison [10] for a half-submerged cylindrical buoy with an aspect ratio of 1.0 shows that the added mass and damping coefficients are quite similar. Therefore, it is reasonable to expect the sphere equations to give at least an order-of-magnitude approximation of a cylindrical buoy.

The small displacement assumption deserves some further comment. For wavelengths of the order of the buoy diameter one would expect the buoy motion to be small. However, as the wavelength increases the buoy motions increase. Since most of the wave energy is expected in the longer wavelengths, the buoy could be expected to see large motions which would cause these equations to be inaccurate. When no ship is in the system, this inaccuracy could be serious. Fortunately, the ship motion becomes a significant effect in the longer wavelengths

and the buoy motion is dominated by the ship movement as transmitted through the hawser and reacted by the mooring line. In this case the contributions from the buoy itself (though in error) would generally be insignificant. For the shorter wavelengths, the ship appears nearly fixed and the exciting forces due to wave action on the buoy become important. It is fortuitous that this is the range in which the buoy equations are most accurate.

2.1.10 Deep Sea Ship's Moors

The basic components required in modeling deep sea mooring systems for surface ships are:

a) surface ship
b) mooring lines (usually submerged)
c) mooring buoys
d) hawser (usually in air and subjected to wind loads)
e) floats, sinkers and anchors

Each of these components have been dealt with to some extent in the previous discussion. Unfortunately it is not possible to develop a fully general non-linear analysis of ship's mooring dynamics. The primary reason for this is the highly complex nature of the interaction between the sea and surface bodies such as ships and mooring buoys. The equations presented for these bodies are linearized equations which address only the response to harmonic, long-crested waves.

The theoretical approach used in dealing with mooring systems follows through a series of approximations. The first step is to obtain a description of the mooring system in the quiescent state where only gravity loads are involved. This is called a dead load analysis. There are some pitfalls in this step which are related to the geometric nonlinearity of the problem. One does not usually know, a priori, what the dead load configuration of the system is and the terms in the static equations are configuration dependent. This is the so-called initial configuration problem and it is dealt with in some detail in Reference 2. Sections 2.2.7 and 3.5 also discuss the problem.

The active loads on the mooring system are assumed to be winds, surface and subsurface currents and surface waves. The effect of surface waves is primarily a dynamic phenomenon while the static or steady-state effects of winds and currents predominate. Therefore, it is assumed that the active loads on the system can be separated into a static effect, which is primarily due to winds and currents, and a dynamic effect from surface waves.

The next step in the analysis is then a static analysis to obtain the response to winds and currents. This is referred to as a live load analysis and it may include point loads representative of imposed work loads. Nonlinearities in the system also play an important part in a live load analysis. The geometric nonlinearity is still present. A significant new nonlinearity comes from the nonconservative, position dependent loads. The flow induced loads are strongly dependent on the orientation of the various elements and the loads change direction and magnitude as the system changes shape and position.

Material nonlinearities also play an important part at this stage. The most pronounced effect comes from the fact that the lines cannot support compressive loads. Should the imposed loads cause any of the legs to go slack (usually in taut moors with neutrally buoyant lines) the material stiffness goes to zero and the group of elements involved with the leg are part of an unstable structure and the stiffness matrix becomes singular.

An important feature in slack moors (negatively buoyant legs) is their ability to resist loads by changing shape and by lifting line or laying it down at the bottom. Modeling this interaction with the bottom using reasonably long cable elements produces some approximations that must be kept in mind while interpreting the results.

In certain situations it is not possible (or feasible) to obtain a dead load configuration and then proceed to the live load analysis. Direct solution for the combined dead and live loads is usually required in these cases. One example is the solution for a single point moor. In this case the quiescent state is of little value and solution for the combined effects is usually quite

easy to obtain if one has a good estimate of the total horizontal load to be supported by the moor. Another situation where this procedure may be required is in dealing with taut moors where legs go slack. In this case the slack legs could be ignored (not included in the model) and the dead load included in the live load analysis.

The analysis of wave induced dynamics begins with the static configuration developed by the wind and currents. Of necessity this is a frequency domain analysis. The equations presented for the ship and mooring buoy dynamics were obtained by assuming the excitation was from a harmonic wave. The linearization process renders the equations frequency dependent and limited to small motion amplitudes.

The incremental equation (2-36) with the load rotation term neglected and the reference state taken to be ${}^{t}C$ (where ${}^{t}C$ is the static reference state) can be used to represent the motion in the frequency domain. In this case the only nonzero elements of $\{\Delta \overline{f}\}$ are those contributed from the surface buoys and ship. Assuming these forces are harmonic, equation (2-36) can be written

$$[M]\ \{\ddot{u}\} + [C]\ \{\dot{u}\} + [K_T]\ \{u\} = \{F\}\ e^{i\omega t} \tag{2-67}$$

Here the reference indices have been dropped and it is understood that $\{u\}$ represents the incremental displacement, $\{\Delta q\}$, from ${}^{t}C$. The vector $\{F\}$ is a set of complex force amplitudes. Assuming the equation is linear and transient effects damp out the response has the form

$$\{u\} = \{U\}\ e^{i\omega t} \tag{2-68}$$

where $\{U\}$ is a set of complex response amplitudes and ω is the circular frequency of the driving function. Substitution of equation (2-68) into (2-67) yields

$$(-\omega^2\ [M] + i\omega\ [C] + [K_T])\ \{U\} = \{F\} \tag{2-69}$$

Solution of this set of complex simultaneous linear algebraic equations gives the dynamic response amplitudes. The magnitude of the response in each degree of freedom is given by

$$|U_i| = U_i \, U_i^* \tag{2-70}$$

where U_i^* is the complex conjugate of the ith component of {U}. The phase shift between the incident wave and the response is given by

$$\phi_i = \mathrm{Tan}^{-1} \frac{I_m (U_i)}{R_e (U_i)} \tag{2-71}$$

A phase shift of zero corresponds to the response being in phase with the incident wave at the ship's reference point.

The dynamic tension response in each element is obtained by adding the displacement increments to the nodal positions, recalculating the element tensions from the constitutive relations using the new lengths, and subtracting the tensions in the static reference state.

2.2 PROGRAM IMPLEMENTATION

2.2.1 Static Solution Procedures

The SEADYN/DSSM program offers three basic solution methods for static analyses. The various features of each of them are discussed at length in Reference 2 so only a brief description will be given here.

The first method is a sequence of linear increment (SLI method). The loads are divided into a sequence of increments and the basic incremental equation (2-39) is repeatedly applied. The SLI method requires the regeneration of the incremental stiffness matrix at each step to reflect the changes in position and constitutive relations. It has the undesirable feature of drifting from the correct solution through accumulating errors and small increments are required for accuracy.

The second method works with the incremental equation (2-40). The first step is identical to the SLI first step, but on each succeeding step the force residual from the previous step is fed back as a corrector. For this reason it is called the residual feedback method (RFB). Although it is a non-iterative method it tends to be self-correcting. On responses which are reasonably well behaved (particularly monotonic responses) the RFB method gives accurate results with significantly fewer steps than does the SLI method. The RFB method costs somewhat more per step because of the residual calculation. The recalculation of the incremental stiffness matrix is still required at each step.

A more general method which employs iterations to solve equation (2-38) is known as the modified Newton-Raphson method (MNR). It begins with an estimated configuration and uses an estimate of the tangent stiffness matrix to obtain successive displacement increments which hopefully lead to a zero force residual. Being an iterative method it is by far the most accurate of the three methods. This accuracy is not free, however. In the first place the method is not unconditionally convergent and the size of the load step required to assure convergence is not easily determined. In some cases it may be extremely small. In ill-conditioned systems it may not be possible to get convergence without some special auxiliary procedures.

The general form of the MNR method is

$$
\begin{aligned}
[\overline{K}]\ \{\Delta q\}^{(i+1)} &= \{R\}^{(i)} \\
\{q\}^{(i+1)} &= \{q\}^{(i)} + \{\Delta q\}^{(i+1)}
\end{aligned}
\qquad (2\text{-}72)
$$

where the superscript i refers to the iteration step. The $[\overline{K}]$ matrix is referred to as an estimator matrix. If $[\overline{K}]$ is the incremental matrix $[\overline{K}_T]$, and it is recalculated at each iteration, the usual Newton-Raphson procedure is obtained. If $[\overline{K}]$ is an approximation of $[\overline{K}_T]$ and/or it is not recalculated at each iteration one has a modified Newton-Raphson method. When $[\overline{K}]$ is not changed and the response curve is monotonically increasing function the successive estimates will

usually oscillate about the correct solution. If the step size is small enough the estimates will tend towards the solution (converge). If the step size is too large the estimates will diverge.

Once oscillating estimates are detected, various accelerating procedures can be employed, and in some instances they will work even when the oscillations are divergent. The program detects oscillations by monitoring the degree of freedom with the largest initial response (i.e., largest component of $\{\Delta q\}^{(1)}$. Oscillation is signalled by repeated sign changes of the critical $\{\Delta q\}$ component. The simplest acceleration scheme averages the two alternating estimates using the sizes of the critical components to weight the average. An optional procedure uses a one-dimensional search to seek a close estimate of $\{\Delta q\}$ which crosses the correct solution. This search is initiated when the ith iteration signals a large oscillation. The search begins at the $(i-1)^{th}$ position and takes small steps in the direction of the i^{th} increment. A new step is tried at each position until the new increment reverses direction. At this point the last two positions are averaged to get a new starting estimate for the iteration. The size of the step used in this 1-D search is controlled by input. The input factor is the fraction of the i^{th} step which is taken as the first step of the search.

Various options are provided to measure convergence of the iterations. Reference 2 should be consulted along with Section 3.2.3.2 for discussions of the convergence criteria.

Various load incrementing options are provided with the static analyses. In general, the gravity load will be increased in increments in a dead load analysis. Fluid induced loads are increased in increments during live load analyses. Both analyses allow point loads which are incremented from zero to the specified value, held constant, or reduced from the value to zero. It is usually assumed that gravity loads are held fixed during a live load analysis, but an option is provided which allows gravity load to be incremented during a live load analysis.

When ships are used in a static analysis the ship is constrained to remain on the surface. This normally means the ship is fixed in heave, roll and pitch. It is possible to input stiffness terms to allow small heave and angular motions out of the surface plane. No checks are made on the magnitude of those responses, so the user is warned to evaluate the validity of his results when these stiffnesses are used.

2.2.2 Time Domain Dynamic Solutions

The SEADYN/DSSM program provides for four different time domain solution methods. Each of them utilize the following set of forward difference equations to develop the solutions:

$$
\begin{aligned}
{}^{t+\Delta t}\{q\} &= {}^{t}\{q\} + \Delta t\ {}^{t}\{\dot{q}\} + \frac{\Delta t^2}{2}\ {}^{t}\{\ddot{q}\} + \alpha\,\Delta t\ ({}^{t+\Delta t}\{\dot{q}\} - {}^{t}\{\dot{q}\}) \\
&\quad + \beta\Delta t^2\ ({}^{t+\Delta t}\{\ddot{q}\} - {}^{t}\{\ddot{q}\}) \qquad\qquad (2\text{-}73) \\
{}^{t+\Delta t}\{\dot{q}\} &= {}^{t}\{\dot{q}\} + \Delta t\ {}^{t}\{\ddot{q}\} + \gamma\Delta t\ ({}^{t+\Delta t}\{\ddot{q}\} - {}^{t}\{\ddot{q}\})
\end{aligned}
$$

where Δt is the time step and α, β, and γ are integration parameters. The usual Newmark formulas are obtained with $\alpha = 0$.

When equations (2-73) are augmented with a motion equation for the system, one has three simultaneous differential equations with the nodal displacements, velocities and accelerations at ${}^{t+\Delta t}C$ as unknowns. Specific forms of the solutions routines for this set of equations are developed in Reference 2. Only the final forms will be presented here.

Direct Iteration Method (DI)

This method uses equations (2-73), (2-35) and (2-26) to obtain an iterative formulation. The form is

$$ {}^{t+\Delta t}\{q\}^{(n+1)} = {}^{t+\Delta t}\{q\}^{(n)} + (\alpha\gamma+\beta)\,\Delta t^2\,\Delta\left({}^{t+\Delta t}\{\Delta\ddot{q}\}^{(n+1)}\right) $$

$$ {}^{t+\Delta t}\{q\}^{(n+1)} = {}^{t+\Delta t}\{\dot{q}\}^{(n)} + \gamma\Delta t\,\Delta\left({}^{t+\Delta t}\{\Delta\ddot{q}\}^{(n+1)}\right) $$

$$ \left({}^{t+\Delta t}\{\Delta\ddot{q}\}^{(n+2)}\right) = {}^{t+\Delta t}\{\ddot{q}\}^{(n+1)} + [M_o]^{-1}\left({}^{t+\Delta t}\{R\}^{(n+1)} - {}^{t+\Delta t}[M_{NL}]^{(n+1)}\right. $$

$$ \left. {}^{t+\Delta t}\{\ddot{q}\}^{(n+1)}\right) \qquad (2\text{-}74) $$

The iteration can be started with equations (2-73) with $\alpha = \beta = \gamma = 0$ or with the residual feedback solution to be described below. The DI method has been shown to be an accurate and cost effective approach. Since it is an iterative method which retains all of the nonlinear terms it readily deals with all of the important nonlinear effects such as position dependent loads and constraints slack segments, and changing geometry. Of particular interest is the ease with which problems with defined motion are dealt with. When problems require the imposition of a known motion (e.g., cable towing problems) the moved node is simply held at the required dynamic state during the iterations.

Sequence of Linear Increments (SLI)

This method starts from equations (2-73) and uses the incremental form (2-36). An iterative solution is also employed, but it has been shown that this method costs essentially the same as the DI method and is much less accurate [2]. It, too, is capable of solving the moving boundary problem but an augmented global stiffness matrix involving the moved degrees of freedom is required. This increases the storage requirements, reduces the speed and increases the numerical error potential.

Residual Feedback Method (RFB)

Equations (2-73) are inverted and substituted into the incremental form (2-37). The result is

$$ [K_{eff}]\,\{\Delta q\} = \{f_{eff}\} \qquad (2\text{-}75) $$

where

$$[K_{eff}] = [K_T] + \frac{1}{\Delta t^2 \beta} [M(^t\{q\})]$$

$$\{f_{eff}\} = {}^{t+\Delta t}\{f(^t\{q\}) - {}^t\{g\} + [M(^t\{q\})] (\frac{1}{\Delta t\beta} {}^t\{\dot{q}\} - (1 - \frac{1}{2\beta}) {}^t\{\ddot{q}\})$$

Equation (2-75) is a linear algebraic equation which can be solved by the usual manner. No iteration is required and the method has a self-correcting feature similar to the static RFB method. This method follows more closely the traditional Newmark implicit integration form [14]. It has the unconditional stability features that have made the method so popular. No provision is made for solving the moving boundary problem, however. The fact that the RFB method requires the formation of a global stiffness matrix, the evaluation of a residual and the solution of simultaneous equations reduces its cost effectiveness. This is usually compensated for by using larger time steps.

Modified Newton-Raphson Form (MNR)

This is an iterative method based on a procedure similar to the MNR static solution. The form is

$$[K_T] \Delta ({}^{t+\Delta t}\{\Delta q\}^{(n+1)} = {}^{t+\Delta t}\{R\}^{(n)} - {}^{t+\Delta t}[M]^{(n)} \, {}^{t+\Delta t}\{\ddot{q}\}^{(n)} \qquad (2\text{-}76)$$

$${}^{t+\Delta t}\{q\}^{(n+1)} = {}^{t+\Delta t}\{q\}^{(n)} + \Delta({}^{t+\Delta t}\{\Delta q\}^{(n+1)}$$

$${}^{t+\Delta t}\{\dot{q}\}^{(n+1)} = {}^{t+\Delta t}\{\dot{q}\}^{(n)} + \frac{\gamma}{\Delta t\,(\alpha\gamma+\beta)} \Delta({}^{t+\Delta t}\{\Delta q\}^{(n+1)})$$

$${}^{t+\Delta t}\{\ddot{q}\}^{(n+1)} = {}^{t+\Delta t}\{\ddot{q}\}^{(n)} + \frac{1}{\Delta t^2\,(\alpha\gamma+\beta)} \Delta ({}^{t+\Delta t}\{\Delta q\}^{(n+1)})$$

The iteration is started with

$$ {}^{t+\Delta t}\{q\}^{(0)} = {}^{t}\{q\} + {}^{t+\Delta t}\{\Delta q\}^{(0)} \tag{2-77} $$

$$ {}^{t+\Delta t}\{\dot{q}\}^{(0)} = \frac{\gamma}{\Delta t\ (\alpha\gamma+\beta)}\ {}^{t+\Delta t}\{\Delta q\}^{(0)} + \left(1 - \frac{\gamma}{(\alpha\gamma+\beta)}\right)\ {}^{t}\{\dot{q}\} + \frac{\Delta t(2\beta-\gamma)}{2(\alpha\gamma+\beta)}\ {}^{t}\{\ddot{q}\} $$

$$ {}^{t+\Delta t}\{\ddot{q}\}^{(0)} = \frac{1}{\Delta t^2\ (\alpha\gamma+\beta)}\ {}^{t+\Delta t}\{\Delta q\}^{(0)} - \frac{1}{\Delta t\ (\alpha\gamma+\beta)}\ {}^{t}\{\dot{q}\} + \left(1 - \frac{(1+2\alpha)}{2(\alpha\gamma+\beta)}\right)\ {}^{t}\{\ddot{q}\} $$

where ${}^{t+\Delta t}\{\Delta q\}^{(0)}$ is obtained from an RFB solution. As an alternative to equations (2-77) the iterations can be started from equations (2-73) with $\alpha = \beta = \gamma = 0$.

The accuracy of this method has been demonstrated but its cost per time step does not appear competitive with the DI method [2]. Moving boundary solutions have not been implemented with this solution.

It would appear from the studies done in Reference 2 that the best general purpose solution method of the four is the DI method. On some problems the method may encounter some difficulties, however. The iterations are convergent only for step sizes of the order it takes an axial wave to traverse the shortest, stiffest element. When the imposed forces are slowly varying the routine will attempt to increase the step size beyond stable behavior limits because the motions are small in small time steps and the iterations converge rapidly. Controls are provided to the user to prevent step size increases in this situation.

In some situations the RFB solution may be found very cost effective. Generally this will be in nearly linear systems, which are slowly varying. The user is cautioned against using very large steps with the RFB method since gross errors may result [2].

It should be noted that the diagonal form of the mass matrix, $[M_0]$, is used in each of the above methods. The advantages in storage and solution effort are obvious. It has been shown that with proper selection of the integration parameters, the errors introduced by the lumped mass approximation tend to compensate for those induced by the solution algorithm to give more accurate results. Experience has shown that $\alpha = 0$, $\beta = 1/12$ and $\gamma = 1/2$ is a good choice of parameters. Preliminary observations [2] indicate that a small negative value for α may be beneficial in controlling amplitude attenuations. Values of $\gamma > 1/2$ introduce numerical damping of the higher frequency components while $\gamma < 1/2$ introduces negative damping.

No internal damping terms have been implemented in these time domain solution forms.

2.2.3 Frequency Domain Solution

2.2.3.1 Solutions for Regular Waves

The response amplitudes, $\{U\}$, for a given frequency are obtained by solving the linear simultaneous algebraic equations represented by (2-69). The coefficient matrices for mass and damping must be recalculated for each frequency since the linearization procedure leaves them dependent on the wave frequency.

The damping terms present some further difficulty. In addition to being frequency dependent, the linearized viscous terms are dependent on the amplitude of the response. The ship's roll-damping depends on the roll angle, the buoy rotational damping depends on the rotation angle, and the cable and lumped body damping depend on the lateral displacement amplitudes (see Appendix E). Thus it is seen that the incremental equations are not strictly linear.

An approximate procedure is introduced to deal with this problem. This involves iterative solutions of the equation (2-69) for each frequency. The first solution at a given frequency is calculated assuming a ship's roll angle. The roll angle obtained from the solution is then used along with the other pertinent response amplitudes to recalculate the damping terms and obtain another

solution. This procedure is repeated until two successive estimates of ship's roll are within 1° of each other. It is assumed that buoy and cable damping are less important than ship's roll and are thus converged when the roll has converged. The response is then dependent not only on the wave frequency, but also on the wave amplitude. This means that it is not appropriate to assume a unit amplitude for a given wave frequency with the intent of obtaining a Response Amplitude Operator (RAO) for that wave. It is necessary to have the correct wave amplitude at each frequency. Therefore, the sea spectrum must be used in the calculation of the regular wave responses. Once the steady state response for a given wave frequency and amplitude is obtained, the RAO is estimated by dividing by the wave amplitude.

The program allows the mass matrix to be formed either with the lumped or consistent form of the element mass. The lumped form is used for the fluid added mass terms.

Provisions for internal damping effects are provided in the proportional damping form. Thus

$$[C] = \alpha\,[M] + \beta\,[K_T] \qquad (2\text{-}78)$$

where α and β are proportionality constants. The damping from fluid drag effects on the cable elements must be linearized before it can be used in equation (2-69). This linearization is described in Appendix E.

2.2.3.2 The Steady-State Wave-Induced Drift Forces

Whenever waves encounter a floating body there arises a set of forces which tend to move the body in the direction the wave is traveling. These forces are often neglected since they are usually small in magnitude. These are the so-called second order wave-induced drift forces. They are generally slowly varying compared to the frequency of the incident wave; however, they have an average or steady-state component which may be significant enough to cause an adjustment of the static position of the ship. These forces are directionally dependent and are sensitive to the amplitude of the ship's response to the wave.

The DTNSRDC Ship's Motion File provides a table of coefficients which can be used to estimate the steady-state drift forces after the ship's dynamic response is obtained. It should be noted that these forces do not estimate the dynamic effects, which are at a lower frequency than the incident wave.

The specific form for the drift forces is given in Appendix D in the discussion of the Ship Motion File. The result is a set of forces for the lateral and longitudinal directions and a yaw moment acting at the ships reference point for each wave frequency. It is assumed that the drift forces are cumulative for the various wave represented in a wave spectrum. Therefore, the drift forces for each of the regular waves are accumulated. It is felt that this is a reasonable approximation since the wave amplitude indicated by the wave spectrum is used in response calculation.

These accumulated drift forces can then be used as an additional static loading to adjust the static reference state. If it is felt that this adjustment will affect the regular wave solutions significantly, the user can request iterations on the regular wave solutions and the drift force adjustments to the static reference until sufficiently small changes are found. Either the MNR or RFB solutions can be used to adjust the static reference.

2.2.3.3 Solution Procedure for Random Seas

The superposition of the regular wave responses to represent the response to random seas follows the well established methods from the theory of random vibrations [15]. The sea is assumed to be uni-directional (long-crested) and is described in terms of a generalized spectral energy density function having the following form:

$$S(\omega) = A/\omega^5 \, e^{-B/\omega^4} \qquad (2\text{-}79)$$

Typical values for the parameters A and B are given in Section 3.2.3.10.

The frequencies to be included in the set of regular wave calculations are determined by specifying a frequency increment, $\Delta\omega$, a lower bound ω_{min}, and

and upper bound, ω_{max}. Regular wave responses are then calculated for

$$\omega_i = \omega_{min} + \frac{1}{2}\Delta\omega + (i-1)\Delta\omega$$

$$\omega_i < \omega_{max}$$

At each frequency the incident wave height is determined from the sea spectrum by the following:

$$h(\omega_i) = (\frac{1}{2} S(\omega_i)\Delta\omega)^{1/2} \tag{2-81}$$

(Note that the wave height is twice the wave amplitude.) This wave height is then used to converge on a steady-state dynamic response using the methods described in the previous section.

Let $H(\omega_i)$ represent the response of one of the quantities (nodal displacement component or element tension). The response spectral density of this quantity is then given by

$$S_x(\omega) = HH^* S(\omega) \tag{2-82}$$

The mean square of the response is

$$E[x^2] = \int_0^\infty HH^* S(\omega)d\omega = \int_0^\infty S_x(\omega)d\omega \tag{2-83}$$

The integral is evaluated numerically using the points obtained from each of the regular wave solutions. Thus

$$E[x^2] \simeq \sum_{i=1}^{N} S_x(\omega_i)\Delta\omega \tag{2-84}$$

where N is the number of regular wave components used.

When the response quantities represent the dynamic excursions relative to the static reference state, then their expected values (i.e., their means) are zero. The magnitude of the response is then treated as a static part plus

a dynamic part. The amplitude of the dynamic part is assumed to follow a Rayleigh distribution with a mean-square value which is a function of the area under the response spectrum curve. Assuming the sea spectrum used is based on double the square of the wave height, the mean-square of the response amplitude is the value obtained by equation (2-84) divided by eight. It is possible, then, to make statistical estimates of the maximum response by making statistical estimates of the dynamic part and adding them to the static values obtained in the updated reference configuration.

2.2.4 Natural Frequencies and Mode Shapes

The incremental equations (2-36) without damping or external forces has the form

$$[M]\ \{\ddot{u}\} + [K_T]\ \{u\} = 0 \tag{2-85}$$

If it is assumed that simple harmonic motion occurs then

$$(-\omega^2\ [M] + [K_T])\ \{u\}\ \sin \omega t = 0 \tag{2-86}$$

since $\{u\} \sin \omega t = 0$ only in the trivial case of $\{u\} = 0$, this requires that

$$\det\ ([K_T] - \omega^2\ [M]) = 0 \tag{2-87}$$

Solutions to this equation lead to the natural frequencies and mode shapes of the small displacement free oscillations about the configurations used in expressing $[M]$ and $[K_T]$. An iterative solution is used which obtains all of the natural frequencies and mode shapes for the system.

The primary assumption made in getting the frequencies and mode shapes is that the equations are linear and no significant damping exists. Both of these assumptions may be violated to some extent for underwater cable structures. The option is provided since the frequencies and mode shapes may still be indicative of the structural behavior.

2.2.5 Component Adequacy Checks

The SEADYN/DSSM program provides a unique feature of checking the capacity of the various components of the system against to imposed loads. The three types of checks provided are:

1. Anchors - the loads imposed on the anchor or fixed node are summed and the resultant is compared with the anchor holding power.

2. Buoys - the resultant of the loads in the lines connecting to the buoy is checked against the buoy capacity.

3. Lines - individual cable elements are checked to see if they are loaded beyond their capacities.

The component checks for buoys and anchors follow the procedures outlined in NAVFAC DM-26 and discussed in Reference 9. The component capacities can be input or obtained from the inventory tables developed for the DESMOOR program [9]. The inventories are described in Appendix C.

All of the adequacy checks rely on estimates of the loads at the end of an element. The one dimensional simplex element has only one value of tension associated with it regardless of how long it is, what its weight is and/or how much distributed load it is supporting. The tension associated with the element can be thought of as being at the midpoint of the element. The procedure for modeling distributed loads must be recalled to see how to estimate element end loads. Equations (2-9) and (2-24) both show that the nodal point equivalent loads for distributed loads are estimated using the element shape functions. These end loads represent the loads applied to the end nodes by the element as it supported distributed loads. The total load at each end of the element is then the vector sum of the element tension and the element loads. The direction of the resultant load at each end gives an estimate of the direction the cable lies at that point. In symbolic form the total loads applied to the nodes by the element are

$$
{}^{t}\{f\}_{elt} = \begin{Bmatrix} f_{x1} \\ f_{y1} \\ f_{z1} \\ f_{x2} \\ f_{y2} \\ f_{z2} \end{Bmatrix} = {}^{t}\{g\} + {}^{t}\{f\}_{grav} + {}^{t}\{f\}_{fluid} \qquad (2\text{-}88)
$$

Some ambiguity in the loads applied to anchors results when long elements are used next to the anchor. If the line actually contacts the bottom before the anchor connection (i.e., between the two nodes which define the element), the SEADYN/DSSM Program will not detect this in the solution. When a line check is made the resultant of the forces at the anchors will have a component pulling down indicating the line was hanging below the anchor. This is due to the model not being able to sense the bottom contact and transfer the weight at that point. Detailed and accurate modeling of the line interaction with the bottom requires short elements in that region. Fortunately the lack of modeling detail at the bottom of the line has little influence on the response at the top of the line.

2.2.6 Surface and Bottom Constraints

The foregoing discussion introduces the problem of constraining the model of the system to responses which lie between the natural boundaries imposed by the water surface and the bottom. One does not expect buoys or lines to rise out of the water or lines and anchors to go below the bottom. The SEADYN/DSSM program assumes the surface and bottom are flat and parallel. Checks are made at each step of static and time domain analyses to see if nodes of the system are within the imposed limits. To avoid the costly operation of checking all nodes in the system at every step it is presumed that the critical points are where lumped bodies are located. Therefore, only those nodes are checked. When one of the critical nodes is within a certain tolerance distance of the surface or bottom it is constrained. For buoys or floats this means that the node is held fixed in the vertical direction but free in the lateral directions. All three components are fixed for anchors. Whenever the vertical resultant of all of the element tensions connecting to the point exceeds the sum of the external vertical

loads at that point, then the constraint is released. The external loads are assumed to include the distributed loads from the elements and the weight or buoyant force from the lumped body.

2.2.7 Initial Configuration Problems and Input Generation Schemes

One of the frustrating features of cable analysis is that most cable systems do not have rigidity or spatial stability unless preloads are imposed. The systems are usually so flexible that small changes in preloads cause large shape changes. Noting that all of the static solution methods use a stiffness matrix, one is faced with a problem of getting a realistic estimate of the stiffness matrix which is nonsingular. In many situations it is necessary to have very accurate estimates of the initial configuration before any of the solution methods will work.

Various facets of this problem are explored in Reference 2. Some procedures which may help obtain stable starting configurations are discussed in Section 3.5.

A technique that has proven of some use in overcoming ill-conditioning and even singularities when using the MNR solution is the use of numerical damping. Felippa [16] shows that nonsingular adjustment to the estimator matrix, $[\overline{K}]$ can be generated by adding a matrix of the form

$$\mu B [I]$$

where

$$B = \{R\}^T [\overline{K}] \{R\} / \{R\}^T \{R\}$$

and μ in a user specified numerical damping coefficient. This additional term tends to "stiffen" the estimator matrix and increase the chances for convergence. Section 3.2.3.2 gives some suggestions for selecting μ.

The program also provides for numerical damping to be used with the incremental solutions. This feature should be used with extreme care since it alters the equations of equilibrium. If an appropriate value can be selected

it would be possible to compensate for some of the error in the first incremental step. There is no rational way available to estimate how much damping to use in this case.

The program provides a quick and convenient way of getting starting configurations when negatively buoyant lines are used. If a line between two defined points is a catenary which reaches the bottom with a horizontal tangent somewhere between the two points, then nodes can be generated along that line. The details of the procedure are given in Section 3.2.2.5. The well known catenary equations are used and one or more of the generated nodes are assumed to be on the bottom if the lower defining node is not at the tangent point. The element preloads for the line are also generated and can be assigned to the line elements.

2.2.8 Condensed Equation Format

Whenever the solution procedure calls for a global stiffness matrix, a reduced form of the matrix is generated. First it is assumed that the matrix is symmetric so that only terms in the upper triangle need be generated and stored. Secondly, the equations are assumed to be sparse and ordered in such a way that the nonzero terms lie within a band near the diagonal. The half-bandwidth (the number of terms from the diagonal to the end of the populated band) is given by three times the largest difference between active node numbers on any element in the system. The matrix is then stored in rows which begin at the diagonal and extend to the end of the band. The consistent mass matrix and damping matrix are also generated in this banded form for the frequency domain analysis.

The simultaneous equation solution routines are formulated to operate on the matrix in this condensed form and the full matrix is never generated. A Choleski decomposition procedure is used to solve the equations. The necessary accumulations of products associated in that procedure are done in double precision to help control numerical errors. Solutions of the frequency domain equations are done in complex arithmetic with the real and imaginary parts summed separately in double precision.

The compact storage and special solution routines provide a significant savings in program size and the number of operations required to solve the equations.

3.0 INPUT INSTRUCTIONS

3.1 PROGRAM OVERVIEW

The SEADYN/DSSM Program is constructed to allow a high level of versatility in the types of analysis performed and the detail to which they are pursued. It is a finite element program which, at present, has only one element type (the nonlinear, one-dimensional simplex element in three-dimensional space) plus provisions for surface ships and buoys and lumped bodies (anchors, weights, buoys, etc.). Various types of analyses can be performed, and, in some cases, more than one solution procedure is provided for a given type of analysis. Which solution procedure should be used is very dependent on the problem being analyzed and the level of accuracy desired. The variety is provided with the hope that as the user becomes more familiar with the program and the nature of the problem he is trying to solve, he may be able to "tune" the solution procedure to the problem and obtain the desired accuracy at a minimum cost.

The nonlinear nature of many cable problems and the complexity of the systems and the loads imposed on them put a premium on versatility and flexibility. Rather than attempting to foresee all possible analysis situations and build in general purpose logic to deal with them, the program has been constructed with some basic capability and then provision is made to allow the user to write his own logic when the built-in capability does not meet his needs. Thus in the case of drag coefficients for the cables and lumped bodies, the spatial distribution of fluid flow velocities, and the time variation functions, the user can take the limited capability provided or he can write his own subroutine to generate the data. Ship's characteristics and loading data are assumed to be provided in the form of data files. Mooring component inventories used in adequacy checks are contained in a subroutine which can be altered by the user.

Analysis of nonlinear cable systems requires some basic understanding of the behavior of such systems. It is not the intent of this document to provide that understanding, but some basic principles can be stated. The major nonlinearity in cable systems is usually geometric in nature. This means the structure changes its characteristics as it deforms such that the undeformed configuration cannot

be used to write the equations of equilibrium. This leads to the requirement for treating the loading in stages. For example, it is usually necessary to obtain a solution for the configuration of the system under the action of gravity (Dead load analysis) before one can analyze the effects of currents or imposed motions, etc. Indeed, it is often necessary to apply a given load in a series of increments in order to get a convergent solution.

One basic principle to observe is that the structure may not be stable unless adequate preloading is provided. Unfortunately, it is not usually possible to estimate the shape of a system under preloading with sufficient accuracy to assure a stable numerical description. In the case of an initial dead loaded configuration it may be possible to start from an unstable "guess". This can be done with numerical damping and/or some of the techniques described in Section 3.5.

The program treats a given problem as a series of subanalyses. This usually follows the order listed below:

DEAD LOAD - determine the initial static configuration with only gravity loads acting. (This may include specified point loads to simulate reactions at certain "adjustable" points.)

LIVE LOAD - change of configuration due to current and/or point loads.

DYNAMIC LOAD - Dynamic response to time varying currents, point loads, and/or imposed movement.
OR
Frequency domain response of mooring systems to surface waves.

The configuration at the end of one subanalysis is presumed to be the starting configuration for the subsequent subanalysis. These subanalyses can be skipped or repeated as long as the user has specified consistent starting data for the next subanalysis.

A RESTART option is provided which can be used to save data for various stages of the analysis for later re-use. This option can either be used to resume calculations on a later run or it is possible to return to a previous configuration within the same run and initiate a new sequence of subanalyses. Details of the RESTART option are given in Section 3.2.4.

Another feature provided is an eigenvalue routine which can be called at the end of any of the subanalyses to obtain an estimate of the natural modes and frequencies at the current configuration.

A special option is provided which allows the adequacy of the mooring components to be checked. Component inventories may be referenced for the capacity of the component or the capacity can be input with the request for the check.

The SEADYN/DSSM Program allows the user to choose a coordinate system which is convenient for him. There are only two general restrictions. First, the global system must be a right-handed rectangular cartesian system. Second, whenever gravity loads are used, one of the global axes must be parallel to the direction of gravity. The vertical axis may point either up or down.

The program develops coordinate transformations from the global system to local element coordinate systems. The local system for a cable element is defined by the order and the current position of the nodes given to define it. The local x axis runs from the first defining node through the second. The remaining two local axes are automatically selected to fit the purposes of the specific calculations.

The local systems for mooring buoys and surface ships require more careful consideration by the user. In each of these cases the initial orientation of the local system is implied by nodal input data. The local coordinate system for a surface ship assumes the x axis is parallel with the longitudinal axis of the ship having the origin at the ships reference point (c.g.) and the positive direction pointing aft. The local y axis points positive starboard and the positive z direction is up. The initial angle between the global system and

the local ship system must be given as input on the appropriate node card (see Section 3.2.2.5). Ships require two nodes to define the reference point (one for position and one for angles) plus one additional node for each point where a line is attached - or motion output is desired. These attachment points are designated as slaves to the reference point.

Mooring buoys, or riser buoys, are characterized by a rigid body interposed between the two cable elements and constrained to ride on the surface. Mooring buoys are distinct from lumped buoys since they require four node numbers to define them while a lumped buoy requires only one. The four nodes are used as follows: one for each of the two attachments and two for the buoy center point and its orientation. The local coordinate system for a mooring buoy is generated from the positions of the center and the attachments. The attachment nodes must be slaved to the center node. The dynamic equations used in the frequency domain analysis of mooring buoys presumes that the attachment nodes are co-planar with the center node. Since no checks are made for this situation, the user must be careful to check that himself.

There is no system of units implied in the program's calculations. Therefore, it is necessary to specify all input data in a consistent set of units. All spatial measures (length, diameter, area, etc.) must be given in the same units. Likewise, all force data must be consistent. For example, if the nodal coordinates are given in feet and the applied loads are given in pounds, then element diameters must be given in feet and the load/strain data must be given in pounds. Furthermore, specific weights would then be given in lbs/ft^3. If the time unit used is seconds, then the acceleration due to gravity would have the units of ft/sec^2 and mass would have the units $lb\text{-}sec^2/ft$. Input of conversion factors is provided to allow use of load files, motion files and inventories which have different units than those assumed in the run.

Each analysis performed by the program requires three sets of cards:

<u>ANALYSIS TITLE CARD</u>: An alpha-numeric card used to label the output and identify the analysis.

<u>SYSTEM DESCRIPTION DATA:</u> A set of cards describing the system being analyzed and giving the initial configuration. Provides data on the element materials and connectivity, ship's characteristics, lumped body data, boundary conditions and fluid media characteristics. These cards may be superseded by a RESTART procedure which obtains this data from a previously saved file.

<u>SUBANALYSIS OPTION DATA:</u> A set consisting of two or more cards which identifies the analysis to be performed and the procedures to be used. In addition, the specific data required (e.g., loads, imposed motion, spectral data, etc.) are given. Any number of subanalysis data sets may be associated with one system description set. Remember the need for sequentially consistent subanalysis states.

The specific forms these data sets take are described in the next section. Section 3.3 describes the optional user-supplied subroutines. Problem size limitations are discussed in Section 3.4. The expressions used in calculating the default drag coefficients (those assumed by the program) are summarized in Section 3.6. A description of the component inventories is provided in Section 3.7.

3.2 INPUT CARD DESCRIPTIONS

3.2.1 <u>Analysis Title Card (12A6)*</u>

COLS.	VARIABLE NAME	DESCRIPTION
1-72	HED	Any descriptive title (see RESTART option for special usage).

*FORTRAN format specification

3.2.2 System Description Data

3.2.2.1 Master Control Card (14I5)

1-5	NN	Total number of nodal points
6-10	NFIX	Number of fixed nodes
11-15	MVB	Number of moved nodes
16-20	NSLAVE	Number of slave nodes
21-25	NE	Number of cable elements
26-30	MATT	Number of cable material types (10 max)
31-35	IBUO	Number of lumped bodies (buoys/anchors) (30 max)
36-40	NSHIPS	Number of ships (3 max)
41-45	JDLD	Dead load flag (see note 3)
46-50	JDYN	Dynamic flag (see note 4)
51-55	IBG	Output flag ≠0 prints nodal masses, gravity loads, element slopes, initial and unstrained element lengths
56-60	NGEN	Number of node generation cards provided (see Section 3.2.2.6)
61-65	NSFILE	Number of ships on data file >0 means read data to create the file <0 means file already for use.
66-70	INVY	Component inventory flag 0 inventory acceptable or not used 1 inventory unit conversion required

NOTES:

1. The node numbering scheme is not arbitrary. The following numerical order must be observed:

   NODES WITH ACTIVE DEGREES OF FREEDOM

   these are the basic unknown degrees of freedom. Any node which is not a SLAVE and has one or more motion component, to be solved for.

   MOVED NODES

   nodes with motion completely described in a dynamic analysis. These nodes are assumed fixed in static analyses.

FIXED NODES

boundary nodes which are completely fixed at all times in all subanalyses.

SLAVE NODES

nodes with movement specified as a function of another node (MASTER NODE) through a rigid link transformation. The MASTER NODE is one of the active nodes.

2. In most solution procedures a bandwidth dependent scheme is employed. Active nodes should be numbered in such a way that bandwidth is minimized. This numbering scheme is left up to the user to define.

3. The dead load flag controls the use of gravity loads. Greater than zero means the gravity load is incremented from zero to its full value in a DEAD LOAD subanalysis and has its full value constant in any LIVE, DYN or FREQ subanalysis. Zero means the system is weightless (DEAD subanalysis not to be called for). Less than zero means the gravity loads will be incremented along with the currents, etc., in a LIVE subanalysis; the full gravity loads will be used in any DYN or FREQ subanalyses.

4. The dynamic flag controls the generation of the system mass matrix. Zero means no mass matrix will be formed (DYN or FREQ subanalysis not allowed). Non-zero means a lumped mass matrix will be generated.

5. Up to three ships can be involved in the system, except for the FREQ subanalysis. Only one ship can be involved in that case.

3.2.2.2 Parameter Card (2I5, 7E10.0)

COLS.	VARIABLE NAME	DESCRIPTION
1-5	IDIR	Direction of gravity (signed integer indicating which of the global axes gives the gravity direction)
6-10	INDRAG	Drag model option ≠0 calls for subroutine DRAGCO (see Section 3.3)
11-20	GRAV	Magnitude of gravitational acceleration (LT^{-2})* Typical value 32.17 ft/sec^2
21-30	G1	Kinematic viscosity of fluid (L^2 T^{-1}) Typical value 1.77 x 10^{-5} ft^2/sec
31-40	G2	Specific weight of fluid (FL^{-3}) Typical value 64.0 lb/ft^3
41-50	VAIR	Kinematic viscosity of air (L^2 T^{-1}) Typical value 1.68 x 10^{-4} ft^2/sec
51-60	GAIR	Specific weight of air (FL^{-3}) Typical value 0.0765 lb/ft^3
61-70	SURFCE	Surface Coordinate (position on gravity axis) (L)
71-80	BOTTOM	Bottom coordinate (position on gravity axis) (L)

NOTES

1. It is assumed that the global axes are selected such that one of them coincides with the direction of gravity. Thus IDIR =-2 means that gravity acts in the negative y direction (i.e., +y is up)

2. INDRAG can be used to select user-specified drag coefficients, since it is passed to the DRAGCO subroutine whenever it is called. If it is zero it overrides all other drag coefficient specifications and the program will use the built in or default values described in Section 3.6.

3. If either SURFCE or BOTTOM is non-zero the motion of any node where there is a lumped body will be limited to stay between SURFCE and BOTTOM. When the body is on the surface it has only the vertical component fixed. When on the bottom it may have all three components fixed or only the vertical component. (See JANCR flag of section 3.2.2.9.) The body remains constrained to the surface or bottom until the element forces are sufficient to move it away. (See note 8 of section 3.2.2.9.)

*( ) gives units expected

4. Input for the fluid and/or air terms is required only when the effects of the fluids are to be considered.

3.2.2.3 Inventory Conversion Factors (3E10.0)

Read only when INVY≠0 (see MASTER CONTROL CARD)

COLS.	VARIABLE NAME	DESCRIPTION
1-10	FRCVY	Inventory force conversion factor multiplies weights and strengths
11-20	FLNVY	Inventory length conversion factor multiplies buoy diameters and lengths
21-30	FDIVY	Inventory diameter conversion factor multiplies line diameters

NOTES

1. A zero input or blank field means the factor is 1.0 (i.e., no conversion required).

2. In each case the value obtained from the inventory is multiplied by the given factor to get it into the units implied by the rest of the input data.

3.2.2.4 Ship Load File Data

This set of data consists of a variable number of cards which describe the ships and their load function tables which are to be placed on the ship's reference file. These cards are read only when NSFILE > 0 on the CONTROL CARD. The following cards will be input for each of the ships indicated by NSFILE. The number of ships that can be input is controlled only by the amount of file space available. If NSFILE = 1 the data is read and remains in core (the ship's reference file is not set up in this case). The program assumes the reference file is on logical unit 10.

A complete ship description consists of the following:

SHIP LOAD TITLE CARD
UNIT LABEL CARD
SHIP PARAMETER CARD
WIND CARD
WIND HEADING CARD(S)
WIND FORCE COEFFICIENT CARDS
SURFACE CURRENT CARD
SURFACE CURRENT HEADING CARD(S)
SURFACE CURRENT FORCE COEFFICIENT CARDS

SHIP LOAD TITLE CARD (12A6)

COLS.	VARIABLE NAME	DESCRIPTION
1-72	SHPCAP	Any descriptive title

UNIT LABEL CARD (A6, 4X, A6, 4X, A6, 4X, A6)

COLS.	VARIABLE NAME	DESCRIPTION
1-6	WLBL	Wind Force Label (e.g., "TONS", "POUNDS")
11-16	CLBL	Current Force Label
21-26	LLBL	Length label (e.g., "FEET", "METERS")
31-36	VLBL	Velocity label (e.g., "KNOTS, "FT/SEC")

NOTE: These labels are output with the ship data as a reminder of the units used. They are used for no other purpose.

SHIP PARAMETERS (8E10.0)

COLS.	VARIABLE NAME	DESCRIPTION	
1-10	TSLT	Total ship length	(L)
11-20	TSAE	End projected wind area	(L^2)
21-30	TSAS	Side projected wind area	(L^2)
31-40	TSWL	Water line length	(L)
41-50	TSB	Beam at mid ships	(L)
51-60	TSD	Draft at mid ships	(L)
61-70	TSDSP	Volume displacement	(L^3)
71-80	TSAP	Propeller projected area	(L^2)

WIND CARD (2I5, 6E10.0)

1-5	NWIND	No. of wind velocity tables, maximum is 5.	
6-10	NTHETW	No. of heading in each table, maximum is 20.	
11-20	SCALE	Test scale factor (A means 1/Ath scale).	
21-30	WNDVEL(1)	First wind velocity (smallest)	(LT^{-1})
⋮			
61-70	WNDVEL(5)	Fifth wind velocity	

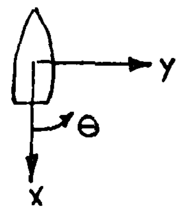
WIND HEADING CARD(S) (8E10.0)

(Repeat as required to get NTHETW entires.)

COLS.	VARIABLE NAME	DESCRIPTION	
1-10	WNDHED(1)	First wind heading	(Degrees)
11-20	etc.		

NOTES:

1. Headings should be between 0° and 360°, listed from the smallest to the largest.
2. If the largest value is 180° the loading functions are assumed to be symmetric about 180° for the end forces and skew-symmetric for the side forces and yaw moments.
3. The angle is measured relative to the ship's local coordinate system.



WIND FORCE COEFFICIENT CARDS (3E10.0)

One card for each heading repeated for each velocity.

COLS.	VARIABLE NAME	DESCRIPTION
1-10	WNDCOE (I, 1, J)	End force coeff. for Ith heading and Jth velocity.
11-20	WNDCOE (I, 2, J)	Side force coeff. for Ith heading and Jth velocity.
21-30	WNDCOE (I, 3, J)	Moment force coeff. for Ith heading and Jth velocity.

(I varies before J).

SURFACE CURRENT CARD (2I5, 6E10.0)

1-5	NCRNT	No. of current tables.	
6-10	NTHETC	No. of headings in each current table	
11-20	TDEPTH	Test water depth	(L)
21-30	CURVEL(1)	First current velocity (smallest)	(LT^{-1})
⋮			
61-70	CURVEL(5)	Fifth current velocity	

SURFACE CURRENT HEADING CARD(S) (8E10.0)

(Repeat as required to get NTHETC entries.)

COLS.	VARIABLE NAME	DESCRIPTION	
1-10	CURHED(1)	First Current Heading	(Degrees)
11-20	etc.		

(See notes for WIND HEADING CARD.)

SURFACE CURRENT FORCE COEFFICIENT CARDS (3E10.0)

(One card for each heading repeated for each velocity.)

1-10	CURCOE(I, 1, J)	End force for Ith heading and Jth velocity
11-20	CURCOE(I, 2, J)	Side force for Ith heading and Jth velocity
21-30	CURCOE(I, 3, J)	Moment force for Ith heading and Jth velocity

(I varies before J.)

3.2.2.5 Nodal Point Cards (2I5, 3E10.0, 3I5, 5X, A6)

COLS.	VARIABLE NAME	DESCRIPTION
1-5	I	Node number
6-10	KSKP	Node generation code (see notes)
11-20	XO(3*I-2)	x
21-30	XO(3*I-1)	y Global Coordinates of Node (I)
31-40	XO(3*I)	z
41-45	NODFIX(3*I-2)	x Constraint codes for components
46-50	NODFIX(3*I-1)	y 0 = free component 1 = fixed component
51-55	NODFIX(3*I)	z -I = means buoy at this node is on the surface and this component is attached to surface until buoy is pulled under -M where M ≠ I means this node is a slave to master node M
61-66	DFLAG	"DEGREE" when nodal coordinates are angles to give headings for ships and the angles are in degrees. Otherwise the angles are assumed to be in radians.

NOTES

1. Input of nodes need not be in numerical order, but the last node (highest node number) terminates the reading of nodes and must be input last. Omitted nodes can be generated using a straight line with uniform spacing with the aid of the KSKP parameter. If KSKP ≠ 0 on a node, then that node is designated as the last node on the line and the one input preceding it is designated as the first node on the line. Nodes are generated evenly along the line between these two points with node numbers incremented by KSKP from the first to the last node. The difference between the node numbers at the ends of the line must be an integer multiple of KSKP, and KSKP cannot be negative. The generated nodes will have the same constraint codes as the first node on the line. More general node generation schemes are available in Section 3.2.2.6.

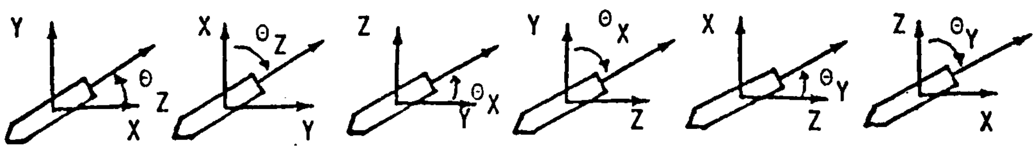
2. All of the NN nodes must be accounted for in the combined specifications for nodes and generation schemes. See MASTER CONTROL card for notes on numbering restrictions.

3. Nodes which define the position of ships or mooring buoys must allow for two nodes in succession. The first node defines the spatial position and the node immediately following gives the headings of the local coordinate systems for the bodies. (See Section 3.1 for a discussion of coordinate systems.) Since both the ships and mooring buoys can introduce very soft components in combination with very stiff components it is recommended that these nodes be numbered at the end of the active nodes to minimize ill-conditioning effects in the solution.

4. All attachment points on a ship must be slaved to the node defining the position of the ship. The program imposes no limit to the number or relative location of these attachments.

5. Mooring buoy frequency domain equations presume only two attachments in addition to the center node. Both of these attachment nodes must be slaved to the node defining the position of the center node. The node numbers for these attachment points are also required on the input for the mooring buoy (Section 3.2.2.8). It is possible to slave more attachments to the buoy center node, but two attachments must be identified as primary ones and their node numbers provided on the buoy cards if a frequency domain solution or component adequacy check is requested.

6. The initial orientation of a ship relative to the global coordinate system must be input. The angle required in this definition can be seen in the following sketch. (The global axes are x, y, z and the local ships axes are 1, 2, 3.)



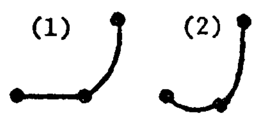
7. Displacement constraint codes (except master node flags) are intended for use only on ACTIVE nodes, i.e., those node numbered before MOVED, FIXED and SLAVE nodes. (See note 1 Section 3.2.2.1.) They produce displacement fixity, but they do not reduce the number of equations. Globally fixed nodes can be numbered as FIXED nodes to remove them from calculations. MOVED nodes have an implied FIXED status in all but DYN subanalyses. Nodes with lumped bodies may change their constraint codes as surface/bottom interaction is treated.

8. Slave nodes need not have elements connected to them. This allows the investigation of the response of specific points on a ship at locations other than the attachments of mooring and working lines.

3.2.2.6 Node Generation Cards (7I5, 5X, 2E10.0)

Required only if NGEN ≠ 0 (Master Control Card)

COLS.	VARIABLE NAME	DESCRIPTION
1-5	NUMN	Number of nodes to be generated
6-10	N1	Node at beginning of line (lowest node on a catenary)
11-15	N2	Node at end of line (highest node on a catenary)
16-20	KSKP	Node number increment
21-25	NBC	Boundary Condition Option 0 - do not copy constraint codes but set all generated nodes to zero 1 - copy from node N1 2 - copy from node N2
26-30	NFIRST	First generated node (default = N1 + KSKP)
31-35	NCAT	Generation Code 0 - straight line 1 - Catenary with lower limit 2 - Catenary without lower limit
41-50	GCATW	Weight/length of generated catenary (FL^{-1})
51-60	GCATH	Horizontal component of tension (F)



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NOTES

1. Both nodes, N1 and N2, must have been defined on previous node cards or generation cards.

2. The node number increment may be either negative or positive. Incrementing starts with the first node after N1 (NFIRST). N1 and N2 need have no numerical relation to the generated nodes, only the spatial relation is significant.

3. All generated nodes are evenly spaced along the generated line.

3.2.2.7 Cable Element Cards (6I5, E10.0, I5, 5X, 2E10.0, I5)

COLS.	VARIABLE NAME	DESCRIPTION
1-5	I	Element Number
6-10	IT(I,1)	Node number for 1st end of element
11-15	IT(I,2)	Node number for 2nd end of element
16-20	MAT(I)	Material number used for this element
21-25	KOMP(I)	Compression Code 0 = no compression stiffness 1 = can support compression -n = means get element preload from n^{th} generated catenary, then set to zero
26-30	KSKP	Element Generation Code (default = 1)
31-40	SIG(I)	Element preload force, + tension (F) (see notes for options)
41-45	ISIGO	Start up procedure flag - on 1st element only (see notes and Section 3.5)
51-60	DSO(I)	Unstretched length, required only when ISIGO = ± 2 (L)
61-70	EAFAC	Preload factor, used only on the first element when ISIGO < 0. (Default value = 0.001)
71-75	MEDIUM(I)	Fluid medium flag 0 means element is in water 1 means element is in air

NOTES

1. Elements must be in ascending element number order and the first and last ones must be input. If any other elements are omitted they will be generated by using the KSKP obtained from the element card following the omitted elements to increment the node numbers given for the element preceding the omitted ones. All other element data will be assumed to be the same as given by the element given previous to the omitted ones.

2. The startup procedure flag (ISIGO) has four basic options:

   ISIGO = 0

   The preloads are presumed to represent an equilibrium state. The element lengths obtained from the nodal positions are used with these preloads and the constitutive relations to calculate the unstretched lengths. DSO(I) and EAFAC are not required.

   ISIGO = 1 (or -1)

   The configuration represented by the nodal positions is an unstretched compatible arrangement of cables. The preloads (SIG(I)) are merely estimates. The unstretched lengths are obtained from the nodal positions. When ISIGO = -1 the preload estimates are obtained by EAFAC times the initial value of EA in the material constitutive relation. In this case SIG(I) is not input.

   ISIGO = 2 (or -2)

   The configuration represented by the nodal positions is a compatible estimate of the deformed configuration. The values of the unstretched lengths are given on the element cards. Element loads are calculated from the unstretched lengths, stretched lengths represented by the nodal positions, and the material constitutive relations. EAFAC is used to estimate a preload only when the estimated configuration results in a zero preload in an element.

   ISIGO = 3 (or -3)

   The nodal positions are correct only for the constrained nodes (fixed and moved). They do not represent a compatible configuration of the system. Input of the unstretched lengths is required and the element preloads may be estimated by input or from EAFAC (i.e., with ISIGO = -3). The option does not appear to work and its use is not recommended.

3. When a string of elements lies along a catenary curve that has been generated by a node generation card (Section 3.2.2.6), the element load for each element can be obtained from the catenary generation by setting KOMP(I) for each element on the line to -n, where n is the number of the generation card. The element load will be taken to be the catenary tension half way between the two nodes defining the element. KOMP(I) will be set to zero (no compression stiffness) by the program.

3.2.2.8 Cable Material Data (2I5, 3E10.0, 2I5,E10.0/(2.E10.0))

Two or more cards required for each material.

COLS.	VARIABLE NAME	DESCRIPTION
1-5	I	Material number (10 max)
6-10	IDRG(I)	Drag Coefficient Code ≠0 and INDRAG ≠ 0 means drag coefficients will be obtained from subroutine DRAGCO. Otherwise the default coefficients of Section 3.6 will be used.
11-20	DIAM(I)	Cable diameter, used only for fluid load calculations (L)
21-30	G3(I)	Weight per unit length (FL^{-1}) negative means lighter than reference fluid (see cols. 46-50)
31-40	CAMC(I)	Added mass coefficient (default = 1.0)
41-45	ME(I)	Number of points in tension/strain curve (if zero an exponent form is assumed)
46-50	MED(I)	Reference medium code for this material data. 0 means water 1 means air
51-60	TENULT(I)	Ultimate Tension capability of this material (See note 3 for usage)

Next Card(s)

If ME(I) ≠ 0 reads ME(I) cards in the order of increasing tension

1-10	TT(J,I)	J^{th} value of tension
11-20	STR(J,I)	J^{th} value of strain

If ME(I) = 0 reads one card

1-10	TT(1,I)	C_1
11-20	STR(1,I)	C_2

where $T = C_1 \varepsilon^{C_2}$

NOTES

1. When point input is used and data is required outside of the given values, the slope of the last (first) segment is assumed to be continued.
2. Input must be in increasing tension order. Thus materials with compression stiffness must begin by listing the largest compressive load first and progressing to the largest tensile load.
3. The ultimate tension input is used only by the frequency domain dynamic solution. When TENULT(I) is greater than zero the random response estimates for tensions will be factored and compared to the ultimate tension. See Section 3.2.3.10 for further discussion of the factors and usage of TENULT(I).

3.2.2.9 Buoy/Anchor Data (2I5, 3E10.0, 2I5, 2E10.0, 2I5)

One or two cards for each body (30 max)

COLS.	VARIABLE NAME	DESCRIPTION
1-5	IM(I)	Node where body is located
6-10	IDRB(I)	Drag Coefficient Code ≠ 0 and INDRAG ≠ 0 means drag coefficients will be obtained from subroutine DRAGCO. Otherwise the default coefficients of Section 3.6 will be used.
11-20	ADM(I)	Buoyancy (negative means heavier than the fluid) (F)
21-30	DBU(I)	Body diameter (L)
31-40	BLEN(I)	Body length (L) 0 for sphere or lump >0 for in-line cylinder
41-45	JSLP(1,I)	Code A — See Notes for use
46-50	JSLP(2,I)	Code B
51-60	BAMC(I)	Added mass coefficient Default = 0.5 for sphere = 1.0 for cylinder
61-70	SBAMP(I)	Amplitude of surface motion (L)
71-75	IBS(I)	Absolute value is the time function number used in subroutine TVARY when buoy is on surface in time domain solution Negative sign signals this body is a mooring buoy
76-80		Continuation code, read extra data card when this is non-zero.

Extra Data (4E10.0,I5)

Read only when continuation code is non-zero. These values assumed to be zero when card not read.

1-10	BWND(I)	Wind drag coefficient for surface buoy $(C_D * A_W)$ (L^2)
11-20	BSCD(I)	Surface current drag coefficient $(C_D * A_S)$ (L^2)
21-30	BMOM(I)	Mooring buoy mass moment of inertia (FLT^2)
31-40	RELFAC(I)	Holding factor for dynamic surface/bottom constraint (default = 1.001)
41-45	JANCR(I)	Anchor fixity flag(not used on buoys) 0 means fix vertical only 1 means fix all three d.o.f.

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NOTES

1. Lumped bodies (not mooring buoys) may be either an approximate sphere or an in-line cylinder. Cylinders are assumed to have faired ends and their orientation is obtained by averaging the directions of the elements indicated by Code A and Code B. If only Code A is given the slope of that element is used.

2. Mooring buoys require 4 nodes in their definition. IM(I) for a mooring buoy give the node number which defines the position of the buoy center. Node IM(I) + 1 must be reserved for buoy angular response. Code A and Code B give the numbers of the two attachment nodes.

3. When a buoy is on the surface the values on the extra card will be used to calculate buoy loads. If a time domain analysis is being performed the buoy can be given a vertical movement defined by SBAMP(I) and TVARY whenever it is on the surface.

4. Surface buoys are constrained in the vertical direction but are free to move laterally. This constraint remains in force until the line tensions are sufficient to submerge the buoy.

5. Anchors have all components constrained on the bottom until the line tensions are sufficient to support the anchor weight.

6. No more than ten lines can be attached to any buoy/anchor (including mooring buoys).

7. Generation of nodes on a catenary may cause the generation of up to two dummy anchors per catenary when the line is tangent to the bottom before the bottom node is reached.

8. RELFAC represents a dynamic release factor. It is the ratio of the vertical load it takes to overcome the surface/bottom constraint and the weight or buoyant force of the body. It is used only in DYN subanalyses. All other subanalyses use a factor of 1.0.

3.2.2.10 Ship's Data (2I5, 4E10.0/8E10.0/8E10.0)

Three cards are required for each ship.

COLS.	VARIABLE NAME	DESCRIPTION
1st Card		
1-5	ISHIP(I)	Node where ship is located
6-10	LSHP(I)	Load function option -1 search file for equivalent ship 0 use analytical load functions n>0 use nth ship from loading file
11-20	CPROP(I)	Propeller resistance coefficient (default = 1.0)
21-30	CR(I)	Longitudinal resistance coefficient for hull to be used only for analytical functions (default = program calculates one)
31-40	CS(I)	Hull wetted surface coefficient to be used only for analytical functions (default = 2.70)
41-50	CMS	Amidships coefficient to be used to calculate C_R for analytical functions (default = 0.98)
2nd Card		
1-10	SLT(I)	Total length of ship (L)
11-20	SAE(I)	End projected wind area (L^2)
21-30	SAS(I)	Side projected wind area (L^2)
31-40	SLWL(I)	Water line length (L)
41-50	SBEAM(I)	Beam at midships (L)
51-60	SDRFT(I)	Draft at midships (L)
61-70	SDSP(I)	Volume Displacement (L^3)
71-80	APROP(I)	Propeller projected area (L^2)

COLS.	VARIABLE NAME	DESCRIPTION
3rd Card		
1-10	FSFRW(I)	Load table wind force conversion factor (default = 1.0)
11-20	FSFRC(I)	Load table current force conversion factor (default = 1.0)
21-30	FSLEN(I)	Load table length conversion factor (default = 1.0)
31-40	FSVEL(I)	Load table velocity conversion factor (default = 1.0)
41-50	SHIPK(1,I)	Heave restoring coefficient (default = 10^{22})
51-60	SHIPK(2,I)	Roll restoring coefficient (default = 10^{22})
61-70	SHIPK(3,I)	Pitch restoring coefficient (default = 10^{22})
71-80	SHIPK(4,I)	Heave/Pitch restoring coefficient (default = 0.)

NOTES

1. Linearized ship restoring coefficients may be input if desired. Otherwise the ship will be assumed fixed in heave, roll, and pitch during static analyses. During frequency domain analyses the restoring matrix is obtained from the ship motion file.
2. The second card may be left blank if LSHP(I) = n and the moored ship is the same as on file n of the ship loading file (i.e., no similarity scaling required).
3. The conversions factors on the third card multiply the values of force, length, and velocity from the ship loading file to get values consistent with the units implied by the rest of the input data.

4. When analytical loading functions are used the longitudinal resistance coefficient may be input or calculated using a table look up. The total coefficient, C_R, consists of three parts:

C_r = residuary coefficient

C_f = frictional resistance coefficient

ΔC_f = fouling resistance coefficient

The value for C_f is always calculated in the program using

$$C_f = \frac{0.456}{(\log_{10} R_e)^{2.58}} - \frac{1700}{R_e}$$

where R_e is Reynold's Number.

When CR(I) is input it is taken to be $C_r + \Delta C_f$. When it is zero or no input is given, then C_r is obtained from a table and ΔC_f is assumed to be 0.0005.

3.2.3 Subanalysis Option Data

This set of cards is used to specify the analysis activities, select the solution routines and provide the required input parameters. Various sequences of subanalyses are possible. The general rule is that any subanalysis can be performed if an appropriate reference state is defined at the time the analysis is requested. Subanalyses are executed in a sequential manner using the state from input, preceding subanalysis, or RESTART as a starting point. The various options are:

SUBANALYSIS TYPE	DESCRIPTION
DEAD	Static analysis with gravity effects only (possibly including point loads)
LIVE	Static analysis with currents, wind, point loads, and gravity.
DYN	Time domain dynamic response to time variable currents, point loads and/or boundary motion
MODE	Obtain undamped natural frequencies and mode shapes.
FREQ	Get steady-state dynamic response to regular waves and superimpose to get random response estimates using a wave spectrum. (Limited to responses driven by surface ships and/or mooring buoys.)
CHEK	Check the adequacy of lines, buoys and anchors.
NEW	Terminate subanalysis sequence and define a new analysis case, i.e., an analysis title card is read next.
END	Terminate run.

When the NEW option is selected a completely new case can be input or the RESTART option initiated to return to a previous configuration and start a new subanalysis sequence.

A variety of solution procedures are provided. They can be classed as linearized incremental, self-correcting incremental or iterative/incremental. The following is a list of the solution options:

OPTION NO.	DESCRIPTION
0	Iterative/incremental method using a Modified Newton-Raphson (MNR) technique. Iteratively solves the total equations at each load/time step. For dynamic analyses the RFB predictor is used.
1	Purely incremental procedure using a Sequence of Linear Increments (SLI). For dynamic analyses the linearized incremental motion equations are solved iteratively.
2	A self-correcting incremental procedure using the Residual Feedback (RFB) technique. Dynamic solutions obtained with implicit algebraic solution.
(3,4)	Options Deactivated -- do not use.
5	Iterative solution of total equations using the Direct Iteration (DI) Technique. Applies only to DYNAMIC LOAD analyses. The approach is essentially a single step predictor-corrector solution. When the option is given a negative sign the RFB method is used as a predictor.
10	A special starting procedure for static analyses. The first load step is applied in a specified number of sub-steps using the RFB method then each of the following steps using the MNR method. In dynamic analyses this gives a MNR solution with an explicit predictor.

Each of the dynamic time domain analyses assumes some form of the Newmark difference equations. Option 5 is limited to dynamic analyses and option 10 has special limitations as noted. Each of the others can be used for both static and dynamic problems. Moving boundary (moved nodes) dynamic problems cannot be solved using Options 0, 10 or 2. The most efficient solution method for dynamics appears to be option 5, while for static problems some combination of options 0 and 2 (or perhaps 10) should be considered. Option 1 usually requires very small increments for accuracy.

Nonlinear analyses are much more complicated than linear ones. One of the complicating factors is the possibility of incrementally updating the frame of reference for the governing equations involving large displacements.

SEADYN/DSSM operates with three configurations of the structural system in order to solve the equations. They are:

<u>Reference Configuration (^{R}C):</u> The configuration used to describe the element positions and coordinate transformations. The stresses, strains and displacements are described relative to this configuration. It may be changed periodically in the analysis.

<u>Deformed Configuration (^{t}C):</u> The configuration at some specified time or load level. This is the initial configuration in an incremental procedure. The stiffness matrix is written for this configuration relative to ^{R}C.

<u>Incremental Configuration ($^{t+\Delta t}C$):</u> The configuration at the end of a time or load step.

A fourth configuration which represents each element in its unstrained state is implied but not identified as a specific configuration of the system since it may not be possible to satisfy nodal compatibility with the unstrained lengths.

Various combinations of updates of ^{R}C and ^{t}C can lead to various solution procedures. For example, if both the configurations ^{R}C and ^{t}C were held at the starting configuration the incremental procedures reduce to a simple small displacement linear analysis. The usual nonlinear incremental procedure is obtained by updating (moving) ^{t}C after each step. This updating involves the regeneration of the incremental stiffness matrix. With ^{R}C held fixed the procedures are called Total Lagrangian. In this case the Local-to-Global coordinate transformations remain unchanged throughout the analysis. When ^{R}C is updated these transformations must also be updated. Updating or moving ^{R}C at each step leads to a less complicated form for the stiffness matrix but adds the requirement of recalculating the element transformations at each step. Little difference in the results should be expected from different schemes of updating ^{R}C. The major differences come from different round-off accumulations. In the case of large strain of highly nonlinear materials there will be some differences due to the approximation of the Eulerian (updates at each step) incremental constitutive relation using the transformed Lagrangian form.

Each subanalysis is initiated with a Subanalysis Option (SAO) Card. The format of this card is the same for each subanalysis but various interpretations are made of the data on the card depending on the subanalysis type. Various additional cards may be required as the result of the entries on the SAO Card. More specific discussion of the additional cards is given following the description of the SAO card.

3.2.3.1 Subanalysis Option Card (A4, 1X, 15I5)

COLS.	VARIABLE NAME	DESCRIPTION
1-4	TYPE	Analysis Type, DEAD, LIVE, etc.
6-10	INP(1)	DEAD, LIVE: estimated number of load steps DYN: not used MODE: mode shape order flag 0-list mode shapes in order of increasing frequency 1-list in order calculated FREQ: number of load steps to be used on the first of the drift force updates. (default = 10) CHEK: dynamic configuration record number to be checked (0 if previous SAO not FREQ)
11-15	INP(2)	DEAD, LIVE, DYN, (FREQ): number of steps between printing MODE: mode shape output flag 0-print all mode shapes n-print n mode shapes -n-print n mode shapes and also write them on logical unit 20. CHECK: component inventory flag 0-inventory not used 1-otherwise
16-20	INP(3)	DEAD, LIVE, DYN: Solution option number (see section 3.2.3) FREQ: Solution option for drift force updates (only 0 or 2 allowed) (See Note 3) CHEK: component inventory print flag 0-do not print inventory 1-otherwise

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21-25	INP(4)	DEAD,LIVE,DYN, MODE: Update Option flag establish ${}^{R}C$ at beginning and 0-do not update (Total Lagrangian) ≥1-update ${}^{R}C$ at step intervals indicated -1-use ${}^{R}C$ from preceding subanalysis and do not update. FREQ: iteration option flag 0-start from original static reference 1-start from last configuration found
26-30	INP(5)	DEAD, LIVE: Start up option n>1-divide first step into n subintervals (see section 3.5) DYN: not used FREQ: drift force iteration flag 0-do not update configuration for drift forces 1-iterate configurations and regular wave solution -1-update configuration once ±2-same as ±1 except drop the sway and yaw forces and use only the surge force (for single point moors)
31-35	INP(6)	DEAD,LIVE,DYN: number of point loads to be read. negative means use the loads from the preceding subanalysis. FREQ: Component check flag ≠0-form dynamic response file for CHEK on logical unit 04
36-40	INP(7)	LIVE,DYN: fluid load option 0-no current -2-read uniform current card -1-get fluid velocity only once from subroutine CURREN ≥1-get fluid velocity from CURREN each time loads are calculated. FREQ: number of wave headings (default = 1)
41-45	INP(8)	DYN: number of payout/reel-in ends FREQ: mass matrix flag 0-lumped mass 1-consistent mass
46-50	INP(9)	DYN: dynamic initial condition flag 0-static start or continuation of a dynamic analysis, leave nodal velocities as is 1-read initial velocity card and set all nodes to the velocities read FREQ: free ship flag ≠0 means calculate unrestrained ship response
51-55	INP(10) (IBG)	Optional debug output flag (See Section 4.2)

56-60	INP(11)	DEAD, LIVE, DYN: restart file flag 0-do not save file -n-rewind and save every nth output record $n \geq 1$-start with present file position and save every nth output record.
61-65	INP(12)	DEAD, LIVE, DYN(FREQ): Step Size Control Number, step size (options 0 and 5) is increased when iterations converge with this number of iterations or less (default = 2)
66-70	INP(13)	DEAD, LIVE, DYN(FREQ): Iteration Limit, step size (options 0 and 5) is decreased if convergence not obtained in this number of iterations (default = 20)
71-75	INP(14)	DEAD, LIVE, DYN(FREQ): Number of Trials, subanalysis is aborted if step size is decreased this number of times without convergence (default = 3)
76-80	INP(15)	Newton-Raphson Update Interval. Used on solution option 0 to signal how often to recalculate the tangent stiffness matrix. This is a packed word: • Units and tens digits give number of steps before new K_T. • Hundreds and above digits give the number of alternating sign trials on a given step before new K_T (default = 205, i.e., 2 alternating tries and 5 steps)

NOTES

1. If TYPE is "NEW" the next card read is a new Analysis Title Card. If TYPE is "END" the job is terminated. Each of the other subanalysis options are listed below with a summary of the cards that must or may be read in association with the option. The additional cards are listed in the table in the order they must appear in the deck if they are used.

CARD	SECTION	DEAD	LIVE	DYN	MODE	FREQ	CHEK
		SUBANALYSIS OPTION					
Solution Parameter	3.2.3.2	R	R	R	N	R	N
Point Loads and Variation Codes	3.2.3.3	O	O	O	N	N	N
Fluid Velocity	3.2.3.4	N	O	O	N	N	N
Wind and Surface Current Data	3.2.3.5	N	O	N	N	N	N
Time Data	3.2.3.6	N	N	R	N	N	N
Moving Boundary	3.2.3.7	N	N	O	N	N	N
Payout/Reel-in Data	3.2.3.8	N	N	O	N	N	N
Initial Velocity	3.2.3.9	N	N	O	N	N	N
Frequency Domain Data	3.2.3.10	N	N	N	N	R	N
Component Check Data	3.2.3.11	N	N	N	N	N	R

R = Required

O = Optional

N = Not used

2. Dynamic time domain analysis involving surface ships and mooring buoys is very restricted. The program does not generate coefficients for the dynamic response of these bodies, it merely assumes they are rigid connectors of the mooring lines and a place where external loads can be applied. The mass for mooring buoys is included but no mass matrix for ships is generated. Loading from wind and surface currents can only be defined in a LIVE subanalysis. Although the program will act on a request for time domain responses with ships and mooring buoys this option should be regarded as non-operational at present.

3. The solution for frequency domain responses to waves (FREQ) has built into it a LIVE analysis with the MNR solution (option 0) or with the RFB solution (Option 2). It allows the choice of solution method with user-selected step size on the first configuration update at each wave heading. When iterative updates are requested (INP(5) > 0) the value given for INP(4) may alter the solution option used on updates following the first one. If INP(4) = 0 the same procedure is used on each update with the initial static reference. If INP(4) = 1 then the configuration from the previous update is used as a starting point with the MNR solution in one load step. Whenever the MNR solution is used parameters in INP(12) through INP(15) are utilized as well as the convergence parameters from the Solution Parameter Card. This option presumes the ship and moor have been moved into a quasi-static reference configuration by the preceding subanalysis and the loads (point loads, currents, wind, gravity) from that solution remain active. No load related data should be given on a FREQ SAO card. The drift force updates presume the drift forces are in load set 3; therefore, the previous static solution cannot use load set 3 if drift force iterations are requested.

4. The FREQ option presumes there is only one ship and the motion coefficients are obtained from the Ship Motion File.

3.2.3.2 Solution Parameter Card (6E10.0)

COLS.	VARIABLE NAME	DESCRIPTION
1-10	DMU	Numerical damping factor (see note 1)
11-20	RERR	Residual norm error bound, used in the MNR solution only (see note 2) (default = .001)
21-30	DERR	Displacement norm error bound, (see note 2) (default = .001)
31-40	DALPHA	Internal damping multiplier of mass matrix (FREQ only)
41-50	DBETA	Internal damping multiplier of stiffness matrix (FREQ only)
51-60	SRCHFC	1-D search factor 0.0 no 1-D search on alternating estimates <0.0 no alternating estimate check >0.0 the 1-D search initial guess factor
61-70	PARMT	MNR Extrapolation Parameter (default = 0.5)

NOTES

1. The numerical damping factor is used to avoid problems with singular or ill-conditioned stiffness matrices. It has no influence on option 5. It should be used with caution with options 1 and 2 since it alters the stiffness matrix, hence the equilibrium equations, in these two cases. Possible values are

$DMU \geq 1.0$	very heavy
$1.0 \geq DMU \geq 0.1$	heavy
$0.1 \geq DMU \geq 0.01$	moderate
$0.01 \geq DMU \geq 0.001$	light
$0.001 \geq DMU$	very light

If DMU < 10^{-8} and a singularity is encountered then DMU is set to 0.001 and the step is tried again. On a repeated singularity DMU is increased to 0.1 and the step is tried once more. If the singularity persists the calculation is aborted.

2. The error bounds are used to test for convergence of the iterative solutions. RERR is used only in the MNR solutions (option 0). DERR is used in options 0 and 5. The convergence criteria is

$$RNORM \le /RERR/$$
$$DNORM \le /DERR/$$

Where RNORM and DNORM represent norms of the nodal force residual and displacement increments, respectively. Both of these inequalities must be satisfied for convergence of the MNR iterations while only the displacements are checked in the DI method (option 5).

Some flexibility in the form of these norms is available. If the value of RERR is input greater than zero, then

$$RNORM = \left(\sum_{i=1}^{N} R_i^2/N\right)^{1/2} /T_{max}$$

where

R_i = the i^{th} component of the nodal residual
N = the total number of nodal degrees of freedom
T_{max} is the maximum element tension

If the value of RERR is negative, then

$$RNORM = \left(\frac{\sum_{i=1}^{N} R_i^2}{\sum_{i=1}^{M} R_i^2}\right)^{1/2}$$

where

M = the total number of nodal components including the fixed nodes, i.e., the reactions are included in the denominator.

If the value of DERR is greater than zero, then

$$\text{DNORM} = \left(\sum_{i=1}^{N} \Delta(\Delta q_i)^2/N\right)^{1/2}$$

where

$\Delta(\Delta q_i)$ = the i^{th} component of the change in the displacement increment.

If DERR is negative, then

$$\text{DNORM} = \left(\frac{\sum_{i=1}^{N} \Delta(\Delta q_i)^2}{\sum_{i=1}^{N} \Delta q_i^{\,2}}\right)^{1/2}$$

See the discussion of norms in Section 2.

3. The terms DALPHA and DBETA can be used to specify internal damping proportional to the mass and/or stiffness matrix. The assumed form of the damping matrix is:

   $$[C] = \alpha[M] + \beta[K]$$

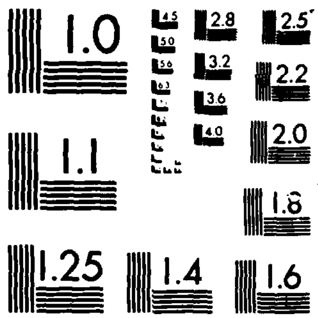
   At the present this is available only on the frequency domain solution.

4. The 1-D search factor, SRCHFC, can be used with the MNR solution (option 0) in an attempt to enhance a poor initial configuration. See the discussion of the MNR method in Section 2.

5. PARMT is an extrapolation parameter used in incremental MNR solutions. The starting estimate for the displacement on all but the first step is the accumulated displacements from the previous step plus PARMT times the change in displacement calculated from the preceding step.

AD-A163 558 DEEP SEA SHIP MOOR VOLUME 2(U) GENERAL ELECTRIC CO 2/2
SYRACUSE NY ELECTRONIC SYSTEMS DIV R L WEBSTER OCT 78
CHES/NAVFAC-FPO-1-78(16)-2

UNCLASSIFIED F/G 13/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

3.2.3.3 Point Loads

Expects INP(6) load cards plus a variation code card

Load Cards (2I5, 3E10.0)

COLS.	VARIABLE NAME	DESCRIPTION
1-5	I	Node where load is applied
6-10	J	Load set number (3 max, default = 1)
11-20	FP(3*I-2,J)	x component of load
21-30	FP(3*I-1,J)	y component of load
31-40	FP(3*I,J)	z component of load

NOTE

If the node I is used for the angular position of a ship or mooring buoy the load is assumed to be a moment about the specified axis with units of (FL). Otherwise the loads are point forces with units of (F).

Variation Code Card (3I5)

1-5	ILF(1)	Load set variation code for set 1
6-10	ILF(2)	Load set variation code for set 2
11-15	ILF(3)	Load set variation code for set 3

NOTE

For DEAD or LIVE

The variation codes signal the variation form during the subanalysis.

1 - increment the load set from 0 to full value

0 - hold load set at full value

-1 - decrease the load set from full value to zero.

FOR DYN

0 hold load set constant at full value

≠0 use the code in subroutine TVARY to obtain the time variable factor (see Section 3.3)

3.2.3.4 Fluid Velocity Card (3E10.0)

One card used only when INP(7) = -2

COLS.	VARIABLE NAME	DESCRIPTION
1-10	VI(1)	V_x
11-20	VI(2)	V_y velocity components of uniform flow field
21-30	VI(3)	V_z

3.2.3.5 Wind and Surface Current Data (6E10.0)

One card used only when NSHIPS ≠ 0 on LIVE subanalysis.

1-10	WIND	Wind velocity (LT^{-1})
11-20	WAD	Initial global heading of wind (degrees)
21-30	CURNT	Surface Current Velocity (LT^{-1})
31-40	CAD	Initial global heading of current (degrees)
41-50	HEDINC	Heading increment (degrees)
51-60	HEDEND	Final wind heading (degrees)

NOTES

1. See Note 6 of Section 3.2.2.5 for global heading convention.
2. When HEDINC is not zero a sequence of static configurations will be generated until the wind heading moves from WAD to $\geq$ HEDEND. The difference between WAD and CAD is held fixed.

3.2.3.6 Time Data Card (6E10.0)

One card required for each DYN subanalysis.

COLS.	VARIABLE NAME	DESCRIPTION
1-10	DT	Time increment
11-20	DTU	Update time increment (used to signal the update of t_C see Section 3.2.3)
21-30	TMAX	Limit time
31-40	GAMNEW	Gamma integration parameter
41-50	BETNEW	Beta integration parameter
51-60	ALPNEW	Alpha integration parameter

NOTES

1. If DTU = 0 or blank DTU is set = TMAX, i.e., no update of t_C.
2. If DT $\leq$ 0 the program will estimate the time step. If the input value of DT = -A then the estimated value is multiplied by A. If DTU = -B then DTU is set to B times the DT estimate.
3. The integration parameters are those from the generalized Newmark difference equations (see Section 2.2.2). The Alpha parameter is not used in the MNR solution routine (solution option 0).

3.2.3.7 Moving Boundary Data Cards (I5, 5X, 3(2I5, E10.0))

One card for each moved node (see Master Control Card)

COLS.	VARIABLE NAME	DESCRIPTION
1-5	I	Moved Node No.
11-15	JB(3*(I-1)+1)	x motion code (see Notes)
16-20	IMTMFN(.+1)	x time function number
21-30	UB(.+1)	x motion amplitude
31-35	JB(.+2)	y motion code
36-40	IMTMFN(.+2)	y time function number
41-50	UB(.+2)	y motion amplitude
51-55	JB(.+3)	z motion code
56-60	IMTMFN(.+3)	z time function number
61-70	UB(.+3)	z motion amplitude

NOTES

1. The motion codes

   1 = displacements are specified
   2 = velocities are specified
   3 = accelerations are specified

2. Non-zero time function numbers are passed to the TVARY subroutine to obtain the time variable factor (see Section 3.3). When the time function number is zero, the motion component is held fixed at the value given.

3.2.3.8 Payout/Reel-in Data (2I5,2E10.0,5I5)

One card for each payout/reel-in end (5 max)

COLS.	VARIABLE NAME	DESCRIPTION	
1-5	JOP(I)	Node where payout/reel-in occurs	
6-10	JPELT(I)	Initial element number for payout/reel '	
11-20	PAYV(I)	Payout rate(+ payout, - reel-in)	LT^{-1})
21-30	AMAXL(I)	Mitosis Length	L)
31-35	NGROW(I)	Number of nodes available for growth	
36-40	NSHRINK(I)	Number of nodes that can be reeled in	
41-45	NNPOI(I)	Node number increment (default = 1)	
46-50	NELPOI(I)	Element number increment (default = 1)	
51-55	NPOVRY(I)	Number for time variation function 0 means constant rate ≠0 means get time variation from TVARY subroutine.	

NOTES

1. Payout/reel-in option not provided under Contract N62477-76-C-0002.

(THIS PAGE RESERVED FOR FUTURE PAYOUT NOTES)

3.2.3.9 Initial Velocity Card (3E10.0)

One card if INP(9) = 1.

COLS.	VARIABLE NAME		DESCRIPTION
1-10	VI(1)	V_x	
11-20	VI(2)	V_y	components of uniform initial velocity
21-30	VI(3)	V_z	

NOTES

1. This card is used in systems such as towed bodies where the initial state is a quasi-static condition where all nodes in the system are moving with the same velocity without accelerating. This option assumes the static configuration is defined by input or was obtained in a previous LIVE analysis with a uniform flow field having the same magnitude as that given here but the opposite sense.

3.2.3.10 Frequency Domain Data Set

This set of data cards is read only for a FREQ subanalysis. The data set consists of the following:

SPECTRUM CARD
SHIP MOTION FILE CONVERSION FACTORS CARD
repeat the following for each heading requested on FREQ SAO card
WAVE HEADING CARD
CALCULATION OPTION CARD
REGULAR WAVE RESPONSE CARDS (Optional)
RANDOM RESPONSE CARDS (Optional)

The Ship Motion File is assumed to be available on logical unit 08 whenever there is a ship in the system. There must be a ship or at least one surface mooring buoy.

SPECTRUM CARD (6E10.0)

COLS.	VARIABLE NAME	DESCRIPTION
1-10	SPECA	Spectrum coefficient A, (L^2 T^{-4})
11-20	SPECB	Spectrum coefficient B, (T^{-4})
21-30	DOMG	$\Delta\omega$, frequency increment (T^{-1})
31-40	OMGMN	ω_{min}, lower bound on frequency (T^{-1})
41-50	OMGMX	ω_{max}, upper bound on frequency (T^{-1})
51-60	AMPMN	Cut-off amplitude for waves, (L) (default = 0.0001, see Note 2)

NOTES

1. The wave spectrum is assumed to have the form

$$S(\omega) = A/\omega^5 \, e^{-B/\omega^4}$$

where $S(\omega)$ is based on twice the square of the wave height. Any spectrum having this general form can be input. Values for common spectra are listed below:

SPECTRUM	A	B
Pierson-Moskowitz	135.0	$9.7 \times 10^4/V_k^4$
Bretschneider	$4200\ H_s^2/T_s^4$	$1050/T_s^4$
I.S.S.C.	$2760\ H_s^2/T_s^4$	$690/T_s^4$

where

V_k = wind speed (knots)

H_s = significant wave height (ft)

T_s = significant wave period (sec)

ω = circular frequency (radians/sec)

$S(\omega)$ = spectral value (ft^2-sec)

2. Regular wave responses are calculated for waves with frequencies between ω_{min} and ω_{max} which have wave amplitudes (based on the spectrum) greater than AMPMN. Incrementing proceeds beyond ω_{max} until a wave amplitude less than AMPMN is encountered.

Ship Motion File Conversion Factors (3E10.0)

COLS.	VARIABLE NAME	DESCRIPTION
1-10	FRCFAC	force conversion factor
11-20	FACLEN	length conversion factor
21-30	TIMFAC	time conversion factor

NOTES

1. These factors are used as multiplifers of the data on the Ship Motion File. Each of them have a default value of 1.0.

Wave Heading (E10.0)

1-10	GHED	Wave heading in global system (degrees) (see Note 6 of Section 3.2.2.5 for global heading convention.)

Calculation Option Card (A5)

COLS.	VARIABLE NAME	DESCRIPTION
1-5	CALTYP	"RAND" for random response "REGb" for regular wave response "DONE" to terminate option

NOTES

1. The word given signals what set of data is to be read next. When CALTYP = "REGb" the next cards read are requests for regular wave responses at specific nodes. When CALTYP = "RAND" the next cards read are requests for random response calculations for various components.

2. These option sets can be repeated as often as desired for a given wave heading. The sequence is terminated with a DONE Card.

Regular Wave Response Data (2I5, 2E10.0, 2I5)

1-5	NODE	Node for which response is requested. Zero means no more data and a new calculation option card will be read next.
6-10	LOCAL	0-produce output in global system 1-produce output in ship's local system
11-20	WFRQ	Circular frequency of response (T^{-1})
21-30	WAMP	Wave amplitude for response (L) (default = 1.0)
31-35	IOCODE	0-output is displacements 1-output is position
36-40	NUM	Number of divisions per cycle (default = 30)

NOTES

1. These cards will generate the displacement versus time or position versus time for all three nodal components through one cycle of motion.

2. The local coordinate system will not be used if position output is requested.

3. There is no limit to the number of requests that can be made. The option is terminated by a blank card (NODE = 0).

Random Response Data (A4, 1X, 2I5, 5X, 4E10.0)

COLS.	VARIABLE NAME	DESCRIPTION
1-4	VTYPE	"NODE", "SHIP", "TENS", "DONE" (see notes)
6-10	NUMC	Node or element number
11-15	NDRT	If VTYPE = "NODE" gives the global component direction 1 = x 2 = y 3 = z
21-30	SFSTAT	Static Load Factor ("TENS" only)
31-40	SF3	(1/3) Load Factor ("TENS" only)
41-50	SF10	(1/10) Load Factor ("TENS" only)
51-60	SF100	(1/100) Load Factor ("TENS" only)

NOTES

1. The spectral response of the ship, element tensions, and any of the nodal displacement components can be estimated. VTYPE signals which one is desired. Any number of these cards may be provided. The input is terminated by a card with VTYPE = "DONE". The response data calculated represent the average of the 1/3, 1/10, 1/100 highest responses.
2. VTYPE = "SHIP" requires no other entries on the card.
3. VTYPE = "TENS" requires the specification of the element number in NUMC. If values are given for SFSTAT through SF100 and if the element material has the ultimate tension specified, then estimates of the factored maximum loads will be printed.
4. VTYPE = "NODE" requires the specification of the node number in NUMC and the component direction in NDRT.

5. One must include a TENS card for each element that will be involved in a subsequent component adequacy check. For example, if a check of an anchor capacity is to be made including dynamic effects, every element which connects to the anchor (or fixed node where the anchor is) must be called out on a TENS Card.

6. The wave heading card and the associated random response data cards must be repeated for each heading requested on the FREQ SAO card as INP(1).

3.2.3.11 Component Check Data (A4, 1X, 3I5, 3E10.0)

Read only for TYPE = CHEK on SAO card.

COLS.	VARIABLE NAME	DESCRIPTION
1-4	CTYPE	"ANCH", "BUOY", "LINE", "DONE"
6-10	NELD	Node or element number
11-15	ICODE	Component code
16-20	JCODE	Bottom factor code
21-30	CAPY	Component capacity (default = use inventory with SAFAC)
31-40	CMPID	Component Identifier for Inventory Anchor Weight Chain Size Line Diameter Buoy O.D. (input in inventory units)
41-50	SAFAC	Safety Factor (default = 1.0)

NOTES

1. CTYPE identifies the type of component to be checked. Only anchors, buoys, or lines are allowed. Any number of cards can be given. Input is terminated by CTYPE = "DONE".

2. Negative ICODE with CTYPE = ANCH means the vertical load will be used in the capacity check.

3. The CHEK SAO can be initiated following any other subanalysis. If the previous one was not FREQ, the present state is evaluated. If it was FREQ and the dynamic response file was generated, the dynamic tensions will be included in the check for those element on the file. (See Note 5 of Section 3.2.3.10)

4. If CTYPE is "ANCH" or "BUOY" then NELD is the node where the anchor or buoy is located. Anchor checks can be made for fixed nodes as well as for active nodes where bodies have been defined.

5. No more than ten lines can be attached to any anchor or buoy at an active node (see Note 6, Section 3.2.2.9). Anchor checks at fixed nodes allow up to twenty lines to be attached to the fixed node.

6. Component Codes

<u>ANCHORS</u>

1. Navy standard stockless with stabilizers
2. NAVSHIPS lightweight
3. NAVFAC stato
4. Imbedment (no inventory)
5. Stock (Admiralty) (no inventory)
6. Mushroom (no inventory)

<u>BUOYS</u>

1. Bar riser chain
2. Spherical or other (no inventory)

<u>LINES</u>

0. Chain
1. Samson 2-in-1 ® braided nylon
2. Samson 2-in-1 ® power braid
3. Samson 2-in-1 ® stable braid
4. Samson Blue Streak
5. Other (no inventory)

7. Bottom factor codes for anchors

   1. Compacted Sand
   2. Stiff dense clay
   3. Sticky clay of medium density (cohesive)
   4. Soft mud (fluid), loose coarse sand, gravel
   5. Hard bottom (rock, shale, boulders)

3.2.4 Restart Capability

It is possible to save the contents of COMMON at each output interval for use as restart data. If a save of the data is requested the contents of COMMON (labeled and unlabeled) are written on tape in a single logical record in the binary mode.

The first record on the tape is the title card from the analysis which creates the tape. The first word in this title may be used as an identifier for the tape. The COMMON restart records are then numbered sequentially after the title record.

The restart files can be saved during a solution sequence by entering a value for INP(11) on the SAO Card. The appropriate values are:

0 Do not save file.

-n Rewind File and Write Title REcord - Then save COMMON.

n Begin saving COMMON from present position on the file (Title Record is written if the file counter is zero.)

where every nth output record will be saved.

The program recognizes the following file codes for saving the data:

FILE CODE	GENERATED BY
01	Dead Load Analysis
02	Live Load Analysis
03	Dynamic Analysis

The restart capability has two functions. First, it allows the restart of the job on a subsequent run in which the contents of the file are to be preserved. This is accomplished by attaching the appropriate file and providing the RESTART input cards. The second function is to allow the user to return to the results of a previous calculation (e.g., multiple live loads from the same dead load configuration). In either case the analysis is treated as a new data case and the three cards given below are required. The normal data sequence can be followed beyond the point of the restart.

3.2.4.1 Title Card (12A6)

COLS.	VARIABLE NAME	DESCRIPTION
1-72	HED	Any title (see below for special usage)

3.2.4.2 Restart Control Card (4I5)

1-5	NFILE	Minus the number of the record to be read from the file (see output heading) 0 means use the last record written in present run
6-10	NTAPE	File Code Number (usually 01, 02, 03, or 04)
11-15		Identification Check Flag 1 - Read the title record from the file and compare 1st 6 characters with the 1st 6 characters in HED (above). Abort if they are not the same 0 - No I.D. check
16-20	IRST	Restart Save Flag (same function as INP(11) on SAO Card)

3.2.4.3 Restart Option Card (A4, 1X, I5, 6E10.0)

COLS.	VARIABLE NAME	DESCRIPTION
1-4		Analysis Type (DEAD, LIVE, DYN, blank) If blank - this signals the contents of the COMMON record are to be the initial conditions for a new load case. The SAO Card is read next. If DEAD, LIVE, or DYN the COMMON record must contain data consistent with the type given or the run is aborted.
6-10	NIPR	New value for number of steps between printing. If this is > 0 and not equal to the value given previously as INP(2), the output interval will be changed by the ratio NIPR/INP(2).
11-20	DTT	New Step Size o New load increment for DEAD or LIVE o New small time step (DT) if DYN o Blank if no change
21-30	DTUT	New Update Time
31-40	TMAXT	New Time Limit
41-50	TGAM	New Value for Newmark's γ
51-60	TBET	New Value for Newmark's β
61-70	TALP	New Value for Alpha

NOTE: Leave columns 21-70 blank if not DYN or DTT = 0.

3.3 USER SUPPLIED SUBROUTINES

Three subroutines are available to be written by the SEADYN/DSSM user and are called if signalled by input data. Each of them are described below.

3.3.1 Subroutine DRAGCO

This subroutine allows the user to specify various sets of drag coefficients. Calls to DRAGCO are initiated when INDRAG $\neq$ 0 on the Parameter Card (Section 3.2.2.2) and either the cable material data (Section 3.2.2.8) or the lumped body data (Section 3.2.2.9) provide a non-zero drag coefficient number. The calling sequence for the subroutine is:

```
SUBROUTINE DRAGCO (INDRAG,IBOD,IDR,RE,RET,CN,CT)
```

where

INDRAG = Option call number

IBOD = 1 for spherical buoy
2 for cylindrical buoy
3 for cable

IDR = drag coefficient number specified by lumped body or cable input data

RE = Reynolds number based on the normal component of the relative fluid velocity

RET = Reynolds number based on the tangential component of the relative fluid velocity (not given on spheres)

CN = Return variable for the calculated normal drag coefficient

CT = Return variable for the calculated tangential drag coefficient (not used on spheres).

INDRAG, IBOD and IDR can be used as indices to select the drag coefficients from user defined catalogs of functions if that is desired.

3.3.2 Subroutine CURREN

This subroutine specifies the spatial and temporal characteristics of the fluid flow field. It will be called once in each subanalysis where INP(7) = -1 (Section 3.2.3.1) or every time the fluid loads are evaluated if INP(7) > 0. The subroutine provides the three components of the fluid flow velocity in the global coordinate system for every node on each call. The calling sequence is:

```
SUBROUTINE CURREN (T,X,N3,V,NFL)
```

where

T = Time at which the current is evaluated

X = Nodal position vector
X(3*(I-1)+J) gives the Jth component at the Ith node

N3 = 3 times the number of nodes

V = The calculated flow velocity components
V(3*(I-1)+J) gives the Jth component at the Ith node

NFL = The flow field number (INP(7) > 0)

3.3.3 Subroutine TVARY

This subroutine specifies the time variation for each of the point loads and/or moved nodes. It is called once for each time variable component at T = 0. and at each time step. The calling sequence is:

```
SUBROUTINE TVARY (T,FNT,IFN)
```

where

T = time for the functional evaluation

FNT = the calculated value of the function

IFN = time function number

3.4 PROBLEM SIZE LIMITS AND FILE USAGE

The SEADYN/DSSM computer program uses implied dimensioning of the COMMON storage area to make it relatively problem size independent. The problem size as indicated by the total number of nodes and elements and the type of analyses requested is checked to see if the COMMON block is large enough to complete the analysis. If it is, the analysis proceeds. If it is not, a message is printed and the rest of the analysis is skipped by searching for the next NEW or END SAO Card.

The size of the COMMON block can be set in the main program which is simply a starter routine for the SEADYN/DSSM program. The main program is:

```
COMMON   A(xxxxx)
NCOM = xxxxx
CALL SEADYN (NCOM)
STOP
END
```

The minimum required values for NCOM for the various subanalyses can be calculated from the following expression.

NCOM $\geq$ NBASE + NSUBAL

where

NBASE = 66*NN + 30*NE
NN = Total number of nodes
NE = Total number of cable elements

The various values for NSUBAL are:

SAO	NSUBAL
DEAD, LIVE, DYN	NF3*IBEND
MODE	2*(NF3+1)*NF3
FREQ	2*NF3*IBEND
CHEK	0

where

NF3 = 3*(NN-NFIX-NSLAVE-MVB*IDYN)

IBEND = half-bandwidth of stiffness matrix
(0 for DYN with solution option 5)

NFIX = number of fixed nodes

NSLAVE = number of slaved nodes

MVB = number of moved nodes

IDYN = 0 for DYN option
1 for DEAD and LIVE options

The value of NF3 used by the MODE and FREQ options is the NF3 from the immediately preceding subanalysis.

The program prints two values for the half-bandwidth when the element input data is processed. The largest value corresponds to the size required by the SLI solution (option 1) when MVB $\neq$ 0 and a DYN SAO is used. The smaller value pertains to all other situations using a stiffness matrix. The two values will be identical when MVB = 0.

The program does place size limits on some of the special features and operations. These limits are summarized below:

Maximum number of material types	= 10
Maximum number of points in any Tension/Strain Table	= 20
Maximum number of moving boundary nodes	= 5
Maximum number of payout/reel-in points	= 5
Maximum number of ships in the system	
DEAD,LIVE,DYN	= 3
FREQ	= 1
Maximum number of anchor/buoys	= 30
Maximum number of lines attached to an active node where anchor/buoy is located	= 10
Maximum number of lines connected to a fixed node for CHEK SAO	= 20
Maximum number of generated catenaries	= 20

These limits are due to assumed array dimensions and can be altered with some minor reprogramming effort.

The program may require the use of various storage files depending on the options and procedures selected. A number of files are directly referenced by the program, while in the case of the RESTART option the file code is read in with the input data. In the latter case the file may be any valid numeric file code that doesn't interfer or conflict with other files used in the run. The following is a list of the files which may receive direct reference by the program. In all cases except the system I/O files they are assumed to be sequential binary files.

FILE CODE	FUNCTION
01	Save RESTART data for DEAD analysis
02	Save RESTART data for LIVE analysis
03	Save RESTART data for DYN analysis
04	Element tension dynamic response file from FREQ to be used in CHEK option
05	System input file
06	System output file
08	Ship Motion File
09	Scratch storage for MODE and FREQ options to save the data from the previous SAO. In addition, the FREQ option writes configuration data for the drift force iterations.
10	Ship's Static Load File
11	Scratch file used in FREQ to store frequency independent portions of motion equations.
12	Scratch file used in FREQ to store the response amplitude operators for the frequency span.
20	Optional file generated by MODE containing natural frequencies and mode shapes.
21	Scratch file for MODE

The files other than 05 and 06 are referenced only when the options selected imply or directly request the use of a file. Those designated as scratch files (09, 11, 12) are used anytime the indicated options are called and they may be overwritten in the progress of the solution. The Ship Motion File (unit 08) is used only as an input file which is reference only for FREQ when there is a ship in the system. The Ship's Static Load File (unit 10) may be generated with input from SEADYN/DSSM or used as an input file. The remaining files are referenced only upon direct request through an input parameter. Unit 01 is written only when INP(11)≠0 on a DEAD SAO. Similarly units 02 and 03 are written only when INP(11)≠0 on LIVE and DYN SAO's, respectively. Unit 04 is written only when INP(6)≠0 on a FREQ SAO. It is expected to be read when CHEK immediately follows FREQ and INP(1)≠0 on the CHEK SAO card. Unit 20 is written only when INP(2)<0 on a MODE SAO card.

3.5 THE INITIAL CONFIGURATION PROBLEM

The use of stiffness methods to obtain the initial configuration of cable systems presents some special problems. Generally the initial lengths and the connectivity of the cables are known but a set of nodal coordinates and consistent element tensions are not. In order to have a nonsingular stiffness matrix (which is required in all of the SEADYN static solutions) "reasonable" estimates of the configuration and element loads are required. One approach is to arrange the unstretched elements in a compatible configuration and assign an arbitrary tension to each of the elements or specify numerical damping. The tension or numerical damping is required since most cable systems are unstable without preloads. Whenever only two unloaded cable elements are connected to a node in three dimensions, there is a singularity. Whether or not there is a singularity with more than two elements at a node depends on the spatial arrangement. By specifying some preload in the elements the stiffness matrix is made nonsingular because of the geometric stiffness term. The introduction of numerical damping (Section 3.2.3.2) also eliminates the singularity by adding a non-zero quantity to each diagonal element of the stiffness matrix. Some caution is necessary when using either an assumed tension or numerical damping with the SLI method (Solution Option 1) since both of them alter the equations of equilibrium and may result in significant solution errors. The RFB incremental solution

(Solution Option 2) is also affected but to a lesser extent because of the self-correcting nature of the method. The MNR solution (Solution Option 0) will not experience any solution errors from this procedure but the rate of convergence and solution stability will be affected.

Often it is not possible to develop a compatible arrangement of elements and maintain their unstretched lengths. This generally occurs in prestressed networks. In such cases a rational approximation of an equilibrium configuration can be used in conjunction with the constitutive relations and a list of the unstretched lengths to estimate the preloads and generate the stiffness matrix. If this approximate configuration results in a singularity the previous device of introducing some artificial tension in critical elements or using numerical damping could be used. In this approach the MNR procedure is the only one that is appropriate.

Each of the above procedures can be initiated by appropriate input on the cable element cards (Section 3.2.2.7). A start with an unstretched compatible configuration (represented by the input nodal positions) using numerical damping to avoid a singularity is obtained by setting ISIGO = 0 on the first element card, leaving all of the element tensions blank, and specifying the desired numerical damping coefficient on the Solution Parameter Card (Section 3.2.3.2). If the tension specification is used, ISIGO = ± 1 and the tensions are input or estimated by the product of the EAFAC and the initial EA from the element constitutive relations.

The third approach is signalled by setting ISIGO = -2 on the first element card and inputting the unstretched lengths on each element card. Tensions will then be estimated from the lengths implied in the nodal input. When an element tension estimate is zero the EAFAC is used as described above.

An additional specification for ISIGO is ± 3. This presumes no estimate of the configuration has been made and the only correct nodal input is the locations of the fixed and moved nodes. The other nodal positions are arbitrary. The element cards then must give the estimated tensions (EAFAC used with ISIGO = -3) and the unstretched lengths. Only the MNR solution should be used with this option. The performance of this technique has generally been unsatisfactory.

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It should be noted that numerical damping can be specified in addition to any of these procedures.

Another device which can be employed with incremental analyses is made available through the SAO Card (Section 3.2.3.1). The input parameter INP(5) allows the first load step to be subdivided into a given number of non-uniform steps. With INP(5) = n the size of each sub-step is given by

$$P_{1i} = \frac{6\ i^2}{n(n+1)\ (2n+1)} \quad P_1 \qquad , \ i=1,\ 2,\ 3,\ \ldots,\ n$$

where P_1 is the size of the first load step. The procedure represents an attempt to minimize the errors induced by the first step and the starting estimate and it can be used with solution Options 1 and 2. Solution Option 10 uses this same procedure with the RFB method until the sub-steps are completed and then shifts to the MNR solution.

Initial configuration determinations with the MNR method on soft systems quite often leads to divergence or very slow convergence requiring very small steps. In such cases it has been found more cost effective to use either of the first two starting procedures (ISIGO = 0 or 1) in conjunction with the RFB solution. Once all of the load steps are completed the final configuration is then used as the initial configuration for a single step MNR correction to the result. This then means that the first two subanalyses would be DEAD LOAD solutions; the first using Solution Option 2 with from 10 to 100 steps and the second with Solution Option 0 with 1 step.

3.6 DEFAULT DRAG COEFFICIENTS

In the event that fluid loading is required and the drag coefficients are not given by the subroutine DRAGCO the program will select the drag coefficients from a set of built-in functions referred to as default coefficients. The default coefficients are used whenever INDRAG = 0 (Parameter Card, Section 3.2.2.2), regardless of the Drag Coefficient Codes on the cable materials and/or the lumped bodies. If INDRAG ≠ 0 the default coefficients will be used for those components which have zero Drag Coefficient Codes.

The default coefficients are:

Spherical Bodies

Reynolds Number, $R_e = \frac{|V|d}{\nu} = \frac{\text{Velocity x body diameter}}{\text{kinematic viscosity}}$

$C_D = 0$ for $R_e \leq 0.1$

$C_D = 0.044 + 13.46/(R_e)^{.5}$ for $0.1 < R_e \leq 1000$

$C_D = 0.47$ for $1000. < R_e \leq 10^5$

$C_D = 0.12$ for $R_e > 10^5$

Cylindrical Bodies and Cable Elements

$$R_e = \frac{|V_N|d}{\nu} = \frac{\text{Normal Velocity x body diameter}}{\text{kinematic viscosity}}$$

$$R_{eT} = \frac{|V_T|d}{\nu} = \frac{\text{Tangential Velocity x body diameter}}{\text{kinematic viscosity}}$$

$C_N = 0$ for $R_e \leq 0.1$

$C_N = 0.45 + 5.93/(R_e)^{0.33}$ for $0.1 < R_e \leq 400$

$C_N = 1.27$ for $400 < R_e \leq 10^5$

$C_N = 0.3$ for $R_e > 10^5$

$C_T = 0$ for $R_{eT} \leq 0.1$

$C_T = 1.88/(R_{eT})^{0.74}$ for $0.1 < R_{eT} \leq 100.55$

$C_T = 0.062$ for $R_{eT} > 100.55$

3.7 COMMENTS ON THE DYNAMIC ANALYSIS OPTIONS

The various possibilities for dynamic time domain analyses range from traditional small displacement linear analyses to fully nonlinear iterative solutions of the total equations. There are three input parameters which control the specification of the solution procedure. These are the Solution Option (INP(3)), the Update Option (INP(4)) and the Update Time (DTU). These parameters control the selection of the solution method (equations used) and the update of ${}^{R}C$ and ${}^{t}C$. The update of ${}^{t}C$ occurs at DTU intervals and ${}^{R}C$ is updated at INP(4)*DTU intervals. Since the tangent stiffness matrix is recalculated only when ${}^{t}C$ is updated it is possible to do small displacement analyses with INP(3) = 1 or 2, INP(4) = 0 and DTU = TMAX. An incremental solution which takes a few linear steps before recalculating the stiffness matrix would result from INP(3) = 1 or 2, INP(4) = n $\geq$ 0, and DT < DTU < TMAX. Fully nonlinear solutions are obtained with solution options 0 and 5. Both represent iterative solutions to the total equations. Option 0 (the MNR method) requires the generation of the tangent stiffness and the selection of INP(4) and DTU will alter the procedures somewhat in regard to the computational effort and some differences in cost and round-off errors may be seen with variations in these parameters. Option 5 does not use the stiffness matrix and thus there is no advantage to be had in updating ${}^{R}C$ and ${}^{t}C$. If the updates are used with option 5 one might expect some slight differences in round-off errors because of the way the displacements are summed.

The iterative solutions allow two types of predictors. An explicit predictor (Newmark Beta = 0) is used for Solution Option 5. An RFB predictor will be used with the DI method with Solution Option = -5. In this case the moving boundary calculations may not be correct since the RFB predictor does not deal with moving boundaries consistently. The MNR solution uses the RFB predictor for Solution Option = 0 and the explicit predictor for Solution Option = 10.

4.0 OUTPUT DESCRIPTION

The SEADYN/DSSM Program provides various types and amounts of output depending on the option selected and the value given for various parameters. Three general levels of output are provided. The first is a reiteration of the input data augmented with supporting data to allow the user to check his specification of the problem. The second is the results of the requested computations. These two constitute the normal output for the program. The next section describes these two levels of output in some detail. The third level consists of various amounts of intermediate calculations which can be used as an aid in input correction, solution optimization and/or program debug. This output is described briefly in Section 4.2.

4.1 NORMAL OUTPUT

The problem input data is output with labels and additional data generated by input request. The final results of node and element generations appear in the output rather than the individual cards that caused the generation. When the system involves ships and data for the ship's loading is obtained from a predefined Ship Load File, the title and unit lables are printed to indicate which set of load data is being used. In a few instances the input data is augmented with additional data to aid in checking the input (e.g., the mass per unit length of cable is calculated and output with the material property input data).

Output for the various subanalyses varies with the type of analysis performed. In addition to listing the pertinent subanalysis input data, the DEAD, LIVE and DYN subanalyses give the spatial position of each node. Values of the nodal velocity are also given for DYN subanalyses. The element tensions are listed at the right-hand side of the page. If there are more elements than nodes the excess element tensions are listed across the page under the nodal output. This set of data is repeated for each requested load or time step. The input parameters INP(1) and INP(2) (Section 3.2.3.1) control the frequency of output for DEAD and LIVE subanalyses. INP(1) gives the number of steps used to

apply the load and INP(2) indicates how many steps are taken before output is printed. The time step, DT, replaces INP(1) in DYN subanalyses. In all cases the state at the beginning of the subanalysis is printed. The results of every step are printed regardless of changes in step size when INP(2) = 1. With INP(2) greater than one, the output interval is held approximately the same even though the step size may change. For example, if the original time step is 0.01 seconds and INP(2) = 5, then output will occur at intervals of 0.05 seconds even though the step size may be altered by the solution procedure. If the step size is changed such that it will no longer generate data at the 0.05 second interval the output will occur as nearly as possible at the 0.05 second intervals. The results for any of the output records can be saved on a file for subsequent restart usage. This is controlled by INP(11). When INP(11) = $\pm$ n then contents of the COMMON storage areas are output on the appropriate file for every nth output record. (See Section 3.2.4 for more details.) When an output record is saved, a message is printed to indicate the record number on the file.

Output for the MODE subanalysis consists of the natural frequency and period and the mode shape for each of the natural modes represented in the model. The solution procedure does not solve for the modes in any specific order but output may be requested in the order of increasing natural frequency. An option is provided to save the frequency and mode shape data on an output file for use external to the SEADYN/DSSM program. The file format is described in the Program Maintenance Manual [5].

The output from the FREQ subanalysis consists of reiteration of the subanalysis input data, identification data from the ship motion file, regular wave solution data, random response results and regular wave results. The identification data printed from the ship motion file are the title, unit labels, ship's parameters, nondimensional wavelengths, headings and roll angles (in radians) as they were obtained from the file. The output data for the regular wave solutions gives the wavelength, amplitude and slope for each wave. If the amplitude is below the specified cutoff value, a message is printed and the calculation proceeds to the next frequency. If the frequency is above the given upper bound and the wave amplitude is below the cutoff, the calculation is

assumed to be completed. When a ship is in the system, the ship response at each frequency is listed in the local coordinate system (surge, sway, heave, roll, pitch, yaw) normalized to a unit wave amplitude. This represents the constrained ship's response after the iterations on roll damping are completed. The data given are the amplitude and phase angles (degrees) for each component. The steady state drift force components for the stated wave amplitude are also given. If INP(9) is not zero the ship response data are given for the unrestrained ship at each stage of the roll damping iterations. This output is preceded by the complex components of the unrestrained ship response (again in the local coordinate system).

When all frequency data has been processed, the total combined drift forces from all of the regular waves are printed. The values given are for surge, sway and yaw. If updates in the static reference state are to be calculated, the output for a LIVE subanalysis will follow. Depending on the option selected, the regular wave solutions will be repeated until the static reference state converges or calculation will proceed to the next stage.

At the completion of the frequency scan and any reference configuration updates, the user has the option of requesting random response calculations and/or detailed data for the regular wave response of any node. Output for the random responses consists of the points in the input and response spectra listed for each frequency and the statistical estimates for the average of the 1/3, 1/10 and 1/100 highest responses. All six components of ship responses are listed in local coordinates. Tension responses give the reference static value and the combined static and dynamic values. If the ultimate strength is provided on the material data card (Section 3.2.2.8) and load factors are given on the random response request (Section 3.2.3.10) then the tension output will also include a listing of the ultimate strength and the sum of the factored static and dynamic components. Random response data for nodes consists of the statistical values (1/3, 1/10, 1/100) for the individual dynamic displacement component in the global coordinate direction. The position of the node in the static reference state is also printed.

Regular wave response output for specified nodes consists of the wave frequency and amplitude for which the results are given, the amplitude and phase angles (degrees) of each of the nodal components and the values of the response through one full cycle. The output may be either the dynamic displacements in the global or ship's local coordinates or the nodal position in global coordinates.

At the completion of the calculations for an individual wave heading the calculations may be repeated for other wave headings or the FREQ subanalysis may be terminated. If a request has been made to save random dynamic response data for subsequent adequacy checks, a message will be printed which identifies the record number on the file which saves the results.

The output for the CHEK subanalysis has three variations on one general form. The general form is a list of the input parameters, a printout of the imposed loading, and messages to signal when capacities are exceeded or unusual situations are encountered. If component inventories are used to get the capacity of the item being checked, the inventory parameter which is closest to the value given in the input will be printed followed by the calculated capacity. This calculation takes the capacity in the inventory, converts it to consistent units and divides by the safety factor.

The capacity checks are made on the state defined when CHEK is called. If the preceding subanalysis was DEAD, LIVE or DYN it deals with the state at the end of the subanalysis. If the preceding subanalysis was FREQ and a nonzero record number is given (INP(1)), the static reference state will be evaluated first and then the increased values for the spectral responses will be printed.

Output for checks of anchor adequacy give the total load and vertical component applied to the anchor. The angle in degrees between the total load resultant and the horizontal is also given. A message is printed if the angle implies the load resultant acts down on the anchor. This is an indication that the line(s) actually touch bottom before reaching the anchor and the model was not detailed enough to sense this. Recall the discussion in Section 2.2.5. If the angle to the resultant load exceeds 3° and the inventory has been used, a message will be printed. If spectral response data has been provided, the

output for the reference state is followed by a listing of the resultant of the dynamic components which represent the average of the highest 1/3, 1/10, 1/100 responses. These are followed by similar values representing the sum of the static and dynamic parts. These are followed by similar lists for the vertical load components.

Output for adequacy checks on buoys is similar to that for anchors. The total resultant load, its vertical component and angle between the resultant and the horizontal are printed. The resultant load should be vertical and the angle should be 90°. This is because the buoy is assumed to have no external constraints in any direction other than vertical and the attached lines must therefore balance the horizontal loading. If the component inventories are used, the buoy O.D. from the inventory which is closest to the input value will be printed. This will be followed by the calculated capacity which is obtained by dividing the upper limit inventory value by the safety factor. If the vertical component of the resultant exceeds the buoy capacity a message will be printed. Spectral response data follows the same pattern as in the anchor case.

Line capacity checks give the nominal line load (the element tension determined in the analysis) and the element end loads which are obtained from the procedures outlined in Section 2.2.5. The global components of the end loads are also given. If the component inventory is used the line diameter from the inventory which is closest to the input value will be printed followed by the calculated capacity (the inventory value divided by the safety factor). A message will be printed if the line capacity is exceeded by the largest of the end loads. Spectral response data given for lines are the dynamic tensions (1/3, 1/10, 1/100) and the combined tensions obtained by adding the largest end load to the dynamic tension estimates.

The CHEK subanalysis also provides for the printing of the component inventories. The output will follow the form given in Appendix C.

4.2 OPTIONAL DEBUG OUTPUT

The integer field in columns 51-55 on the Master Control Card (Section 3.2.2.1) and on the Subanalysis Option Card (Section 3.2.3.1) is used to signal requests for extra output. In general, this output was intended for use in debugging and checkout of the program. It has also been found useful in finding difficult input errors and analyzing the efficiency of various choices of solution methods and parameters. The output is not usually requested and little effort has been expended in generating labels to identify the output. It is assumed that when the higher levels of output detail are requested that the user is familiar enough with the program structure and the solution methods to be able to utilize the data intelligently. Indiscriminant requests for extra output is strongly discouraged since it greatly adds to the output volume and increases run costs.

The Fortran variable IBG is the item read to control the extra output. Generally, low levels of output are obtained by small values for IBG. Thus when IBG is less than 7 only a small amount of specific output is produced. Values of IBG greater than 6 will give significant amounts of output on iterative solutions. The following is a list of the values of IBG recognized in the subanalyses and a brief description of the output they generate. (Frequency codes: I = each iteration, S = each step, F = each wave frequency, H = each wave heading)

IBG	FREQUENCY	EXTRA OUTPUT
$\geq$ 1	S	The number of iterations required to get convergence of iterative solutions (DEAD, LIVE, DYN).
		A message whenever the reference configuration, ${}^{R}C$, is updated.
2	I	A message whenever an element is in compression with no compression stiffness (i.e., slack).
		A message whenever a buoy or anchor changes its status relative to the surface and bottom limits.
		The values of the net vertical forces applied to buoys and anchors.

IBG	FREQUENCY	EXTRA OUTPUT
3	S	The values of nodal displacement, velocity and acceleration in ^tC, the nodal displacement and acceleration at the incremental reference state, the nodal positions and forces in ^tC, for each node.
4	I	Payout update data (not implemented yet)
5	I	Ship's static loads in local and global coordinates.
≥ 6	I	For MNR Solution: five values are printed --- residual norm, displacement norm (the one used), the values for the three alternative displacement norms.
	I	For the DI Dynamic Solution: six values are printed --- the iteration number, the displacement norm, the maximum acceleration increment and the values for three alternative displacement norms.
	F	For the FREQ Subanalysis: the values of the steady state solution vector, the response amplitude operator data for displacements and tensions.
≥ 7	I	For the MNR Solution: A message when the tangential stiffness matrix is calculated. A message when the 1-D search is initiated and terminated.
		Element tensions.
		The values of DMU, BETA and the modified diagonal terms of the tangential stiffness matrix when numerical damping is used.
		A message when alternating estimates are detected and the next "guess" is between them.
		The current positions of the nodes.
	I	For the DI Dynamic Solutions: A message whenever alternating estimates are detected and the next "guess" is between them.
	S	For the RFB Dynamic Solutions: A message when tangent stiffness matrix calculated.
		Element tensions
		Effective loads
		Incremental displacements
	I	For the FREQ Subanalysis: The values of the ship's roll angle.

≥8	I	For the MNR Solutions: Current values of the residual norm, the components of the residual, the force vector, the total displacement, and the incremental displacement.
		IBG is reset to 7 after 5 steps.
	I	For the DI Dynamic Solutions: Current values of the force residual, acceleration increment, and displacement increment.
	I	For the FREQ Subanalysis: The values for the wave induced ships forces (local coordinates), the force vector (global coordinates), steady state response vector.
	F	Details of dynamic tension calculation
	S	For the RFB and SLI Static Solutions: The incremental or effective forces and the displacement increments.
≥9	Once	For RFB Dynamic and MNR Solutions: The terms of the tangential stiffness matrix in compact storage format.
		IBG set to 8 after one printing.
≥10	H	For FREQ Subanalysis: The dimensionalized form of the ships mass and restoring matrices (M_S and K_S)
	I	Diagonal terms of the system matrix, $[K-\omega^2 M + i\omega C]$.
		The parameters used in interpolating in the Ship Motion File.
		The ship's added mass and damping matrices (M_{AS}, C_S) and loading data.
11	I	The values of fluid velocity and fluid induced loads at each node in the system.
		The local and global forms of the ship's static loads (same as IBG = 5)
		The local to global transformation matrix for ships.

≥11	H	The mass matrix in compact form for the mooring system in a FREQ subanalysis.
≥12	Once	The global stiffness matrix in compact form. IBG set to 11 after one printing.
≥13	Once	Each element stiffness matrix and local to global transformation data. The element contributions to the residual. IBG set to 11 after one printing.
14	Once	Same as IBG = 13 except IBG is set to zero after one printing.

A nonzero value for IBG on the Master Control Card will cause the printing of the components of the lumped mass matrix, the residual added mass (the added mass to be removed from the tangential direction), the gravity load vector, plus a list of the direction cosines, the initial length, and the unstretched length for each element in the input initial configuration. This latter output has been found to be very helpful in identifying erroneous node and element input. If IBG = 3 the same data as in the subanalysis list for IBG = 3 will be printed. This represents the initial reference state and all displacements, velocities, accelerations, and forces should be zero. The nodal positions should be the same as those printed in the normal output.

5.0 DATA CHECKS AND ERROR RETURNS

The SEADYN/DSSM program makes some checks of the input data and attempts to aid the user find his errors by printing various messages. No attempt has been made to be comprehensive in this feature since it is very difficult to foresee and/or detect many of the possible errors. During the processing of the subanalyses, checks are made on the validity of the requests and the convergence of the solution procedures. The messages that may be printed are listed below with a brief description of the probable cause and/or cure. The action taken after the error detection is indicated by the following codes:

(F) Fatal, run aborted

(N) Abort analysis case and seek a new problem definition by searching the deck for a NEW SAO card.

(O) Abort present SAO activity and go to the next SAO card.

(S) Skip this request and go to the next card.

(C) Continue calculation with action as indicated.

5.1 SYSTEM DESCRIPTION CHECKS

(N) NODES OMITTED IN GENERATION

Message is followed by a list of ones and zeros (ten per line) corresponding to the nodes in the system. The zeros indicate which nodes were not defined either by input or generation sequence. All nodes must be accounted for. Following the integers the nodal coordinates are printed to aid in finding the error. The problem usually comes from improper node generation input.

(N) CATENARY GENERATION CASE 2 NOT WORKING

Message is followed by five numbers. They are values for the following items:

X_C = the distance from node N1 to the point where the catenary is tangent to the bottom. In this case it will be negative indicating the first node is above the tangent point.

X_T = horizontal distance from node N2 to the tangent point

XSPAN = Horizontal distance between N1 and N2

YSPAN = Vertical distance between N1 and N2

C = H/w for catenary

The option for generating a non-tangent catenary (Case 2) has not been developed. If this was not intended, check the input for the positions of nodes N1 and N2 and the values for H and w.

(N) ELEMENT GENERATION ERROR

First element was not input, or element cards are not in increasing element number order, or last element was not input.

(N) MORE THAN TEN ELEMENTS CONNECTED TO BUOY/ANCHOR xxx

The number given indicates the buoy/anchor number. Array dimensions presently limited to ten. Check element cards or reformulate description.

(N) MOORING BUOY AT NODE xxx HAS TOO MANY SLAVES.
FOUND xxx

Present dimension limits it to ten.

(N) IMPROPERLY DEFINED MOORING BUOY AT NODE xxx
NO. OF SLAVES FOUND = xxx

Mooring buoys require at least two slaves.

(N) SHIP DATA INPUT ERROR ON xxx (Ship No.)
NO. OF SHIPS ON FILE = xxx
LOAD FUNCTION OPTION = xxx

Blank Card for moored ship data requested definition of ship from load file with no load file defined.

OR

Attempted ship scaling with no load file defined.

(F) ERROR IN ($\begin{smallmatrix}\text{WIND}\\ \text{CURRENT}\end{smallmatrix}$) LOAD TABLE ON SHIP xxx
HEADING = xxxx
LAST TABLE ENTRY = xxxx
SYMMETRY FLAG = xxxx

Heading requested which exceeds the largest value in the table. Check ship load input table.

(F) DEPTH CORRECTION ERROR -- SHIPS DRAFT EXCEEDS WATER DEPTH

Gross input error. Check for dropped deck.

(C) WARNING--UNITS DO NOT APPEAR TO BE CONSISTENT
GRAVITATIONAL ACCELERATION FROM TAPE IS xxxx
UNIT LABELS FROM TAPE ARE xxx xxx xxx

The ship motions file conversion factors do not properly convert the GRAV on the file to the GRAV specified in this run. Calculation still proceeds.

(N) TAPE POSITIONING OR FORMAT ERROR
UNABLE TO FIND SHIP DATA
ITEM xxx LAST READ IS FOR HEADING xxxx
AND WAVELENGTH xxxx.
WANTED HEADING xxxx WITH WAVE LENGTH xxxx.

The ship motion file is not formulated properly or other input or equipment malfunction has made reading the file impossible.

5.2 SUBANALYSIS OPTION ERRORS

(N) UNRECOGNIZED ANALYSIS OPTION = xxxx
TRY TO GET TO NEXT CASE

Usually indicates improper numbers of cards or cards out of sequence.

(N) INSUFFICIENT STORAGE TO PROCEED
COMMON SIZE = xxx
STORAGE NEEDED = xxx
HALF BANDWIDTH = xxx
DEGREES OF FREEDOM = xxx
BASE SIZE = xxx

Subanalysis request (DEAD,LIVE,DYN) cannot be processed due to storage limitations. Problem must be reformulated or NCOM increased (see Section 3.4)

(O) NOT ENOUGH STORAGE FOR MODE SHAPES
NEED xxxx, WITH xxxx AVAILABLE

See Section 3.4

(N) NOT ENOUGH STORAGE FOR FREQUENCY SOLUTION
NEED xxxx, WITH xxxx AVAILABLE

See Section 3.4

(F) INCONSISTENT ANALYSIS REQUEST ON RESTART

Attempted a restart of DEAD,LIVE or DYN and the file was not from that type of subanalysis.

(F) TAPE LABEL xxxxxx DOES NOT AGREE WITH xxxxxx

The label check failed on restart. The first six characters on the RESTART Title Card did not agree with the first six characters on the Analysis Title Card which saved the file.

(F) BLANK COMMON ON TAPE LARGER THAN SPACE AVAILABLE

The data saved on the file requires more storage than is presently available. (see Section 3.4) The two numbers printed are the required and current values of NCOM.

(N) NUMBER OF PAYOUT ENDS EXCEEDS LIMIT OF 5

Check problem specifications.

(N) NUMBER OF SHIPS = xxxx
DYNAMIC SOLUTION PRESENTLY LIMITED TO ONE SHIP

Frequency domain solution requested with more than one ship.

(N) SPECTRUM ERROR, NO FREQUENCIES FOUND WITH SIGNIFICANT WAVE HEIGHTS

Check spectrum parameters and/or frequency range.

(N) INVALID COMPONENT TYPE xxxx
ASSUME END OF INPUT

Occurs when random response requests are being processed and a card is encountered which does not have SHIP, NODE, TENS or DONE in columns 1-4. The items to this point are processed and the case aborted with the additional message:

(N) POSSIBLE SEQUENCE ERROR -- CASE TERMINATED

(See previous explanation)
The dynamic response file is not written.

(S) SHIP OUTPUT REQUESTED WITH NO SHIP IN THE SYSTEM

Random response request for ship ignored when NSHIPS $\neq$ 1.

(O) REQUESTED DYNAMIC EFFECTS WITH NO FREQUENCY DOMAIN FILE PROVIDED
ABORT ADEQUACY CHECK

Dynamic response file was not saved in the previous FREQ SAO (see INP(6) on SAO Card).

(O) IMPROPER RECORD NUMBER ON FREQUENCY DOMAIN FILE
ABORT ADEQUACY CHECK

The requested record on the dynamic response file was either zero or greater than the number of records written. Check INP(1) on CHEK SAO Card.

(S) NO DYNAMIC TENSION PROVIDED ON ELEMENT xxxx
IGNORE DYNAMICS

The random response data for this element was not requested by a TENS Card for this wave heading in the FREQ SAO.

(S) CAPACITY AND COMPONENT ID BOTH ZERO
SKIP REQUEST FOR xxxx (CTYPE)

Check input card.

(S) INVALID COMPONENT TYPE
SKIP REQUEST FOR xxxx

The component number is not one recognized by the component inventory. See Section 3.2.3.11 and Appendix A.

(S) THERE IS NO BUOY AT NODE xxx
SKIP REQUEST FOR xxxx

Check node number given.

(S) MORE THAN TWENTY LINES ON ANCHOR AT NODE xxx
SKIP REQUEST FOR xxxx

The fixed node where anchor capacity check is requested has too many elements connected to it to make the check.

(S) NO LINES CONNECTED TO NODE xxx
SKIP REQUEST FOR xxxx

Check node number.

(S) ANCHOR NOT ON BOTTOM AT NODE xxx
SKIP REQUEST FOR xxxx

Anchor weight is not sufficient to hold the lines at this node and it has been lifted off the bottom or has not reached there.

(C) TOO MANY LOAD SETS FOR DRIFT FORCE ITERATION
REFERENCE STATE NOT UPDATED

The previous static analysis used 3 load sets. This leaves no room to store the drift forces.

(C) INVALID NODE NUMBER = xxx
SKIP THIS REQUEST

Regular wave response data was requested for a node number which is less than 1 or greater than the number of nodes in the model.

(C) DATA NOT AVAILABLE FOR xxxx
SKIP THIS REQUEST

Regular wave response data was requested for a frequency outside of the range which was generated on the RAO file.

(N) INVALID CALCULATION OPTION = xxxx
CASE TERMINATED

The frequency domain calculation option was not RAND, REGb or DONE. Cards are out of sequence or card mispunched.

(N) SHIP MOTION FILE ERROR
WAVELENGTHS NOT IN DECREASING ORDER

Check format of Ship Motion File.

(N) SHIP MOTION DATA EXCEEDS LIMITS

	NOB	NOH	NOK	NRV
LIMITS	5	30	30	8
VALUES READ	xxx	xxx	xxx	xxx

The ship motion file has arrays larger than the dimension in SEADYN/DSSM.

NOB = number of Froude Numbers
NOH = number of wave headings
NOK = number of wavelengths
NRV = number of roll angles

5.3 SOLUTION OPTION EXECUTION MESSAGES

(N,S) EQUATION DECOMPOSITION FAILED ON ROW xxx

The simultaneous equations in the subroutine SLVBAN (DEAD, LIVE, DYN, FREQ) or subroutine COMBAN (FREQ) are singular or sufficiently ill-conditioned to appear singular. The row of the matrix is calculated from (3*(I-1)+J) where I is the node number and J is the direction (1, 2 or 3). Check node I for proper constraint. This also occurs in poorly tensioned (soft) initial configurations. Check for zero tensions, etc. (see Section 3.5)

If this occurs with solution option 1 or 2 or in the steady-state response calculations in FREQ SAO the case is terminated.

If it occurs during a MNR solution (options 10 or 0) various attempts are made to remove the singularity and repeat the step. Failing in these, the case is terminated.

(N) ROW xxx OF STIFFNESS MATRIX HAS NEGATIVE DIAGONAL TERM = xxxx

Message follows previous message on solution options 1 or 2.

(C) SINGULAR EQUATIONS WITH NUMERICAL DAMPING FACTOR OF xxxx

This message is printed from the MNR solution. See note 1 of Section 3.2.3.2 for further explanation. This message is printed after the three trials described in that note. This will be followed by a reduction in step size subject to the limits of INP(14) on the SAO Card.

(C) LAST TWO RESIDUAL AND DISPLACEMENT NORMS xxxx xxxx xxxx xxxx KOUNT = xxxx

The four values printed are the residual and displacement norms for iteration i-1 and iteration i in the MNR solution. This message signals an increasing norm indicative of divergence or a lack of convergence in the number of iterations given by KOUNT. This will be followed by a reduction of step size subject to the limits of INP(14) on the SAO card.

(C,N) STEP SIZE REDUCED TO xxxx ON INCREMENT xx
RESIDUAL AND DISPLACEMENT NORMS xxxx xxxx

This message follows the reduction of step size in a MNR solution. It will follow either of the previous two messages when the number step size reductions is within the limits imposed by INP(14) on the SAO card.

(N) DIVERGENCE ON STEP xxx AT xxxxx (load factor or time)

Signals abort of MNR solution after INP(14) successive step size reductions.

(F,N) BUOY/ANCHOR NO. xxx MOVED TOO FAR BEYOND LIMIT IN ONE STEP
DECREASE STEP SIZE

Indicates a check for surface or bottom constraints detected large motion of the body as it approached the limit (e.g., buoy moved out of water more than buoy diameter in one step). On the MNR iterations (solution option 0 or 10) and DI solutions (option 5) the step size will be decreased. In all other situations the run is aborted.

(C) DIVERGING NONLINEAR ITERATION AT TIME xxxx
STEP xx WITH A TIME INCREMENT OF xxxx
LAST TWO NORMS xxxx xxxx KOUNT = xx

Signals a lack of convergence in the Direct Numerical Integration (option 5) time domain solution. The various situations which lead to this message are:

a) Buoy/Anchor moved too far (see previous message)

b) Acceleration more than doubled in one iteration on the component with the largest acceleration.

c) The displacement norm exceeds 1×10^{12}

d) The displacement norm increased in three successive iterations

e) The largest displacement increment exceeds a magnitude of 1×10^{10}

f) Number of iterations exceeds INP(13) on SAO Card. This will be followed by a reduction in time step subject to the limits of INP(14) on the SAO card.

(C,N) TIME STEP REDUCED TO xxxx ON STEP xxxx
NORM = xxxx

This message follows the reduction of step size in a DI solution. It will follow the previous message when the number of step size reductions is within the limits imposed by INP(14) on the SAO Card.

(N) DYNAMIC SOLUTION DOES NOT CONVERGE AT TIME xxxx WITH A TIME INCREMENT OF xxxx
LAST TWO NORMS xxxx xxxx

Signals abort of DI solution after INP(14) successive step size reductions.

6.0 SAMPLE PROBLEMS

No simple set of demonstration problems can explore all of the capabilities of a program such as SEADYN/DSSM. The program was designed to be very general in the types and complexity of problems it can deal with. Even though only one finite element type is presently available in the program, it can deal with a wide variety of problems. Reference 2 explored some of the capabilities and compared the accuracies and efficiencies of the various solution options prior to the introduction of the moored ship capability. Reference 6 deals specifically with the static and dynamic analyses of moored ships, and a number of example problems are presented there.

In this section five sample problems will be presented. Four of them are from the set discussed in Reference 2 and the fifth evaluates the static response of a moored ship to changes in wind and current direction. The input cards for each case are presented with the discussion. It will be instructive for the new user to compare these cards with the input descriptions of Section 3.0.

6.1 THE SNAP-THROUGH RESPONSE OF A TWO-BAR TRUSS

A popular problem for demonstrating geometrically nonlinear effects [17] is a shallow two-bar truss supported by a spring and driven through the snap-through range by a single point load. A comparison of the performance of the three static analysis solution options are compared in Figure 6-1. The input cards for the 3 solutionsare shown in Table 6-1. The data represents the SLI solution followed by restarts to get the MNR and FBK solutions.

6.2 STATIC RESPONSE OF THE SEACON II STRUCTURE

Kretschmer, et al [18], describe a cable test structure known as SEACON II. Figure 6-2 presents the pertinent physical characteristics of the structure. The static response of the system to an ocean current is presented in Figure 6-3. The model was rather crude (2 elements per arm and eight elements per leg) but the intent of the problem was more in demonstrating the solution procedure than in getting accurate results. The structure is quite flexible and it offers a good demonstration of the difficulties encountered in getting a stable dead loaded configuration. The natural starting point for the problem is a compatible arrangement of the unstretched cables. In the final dead loaded

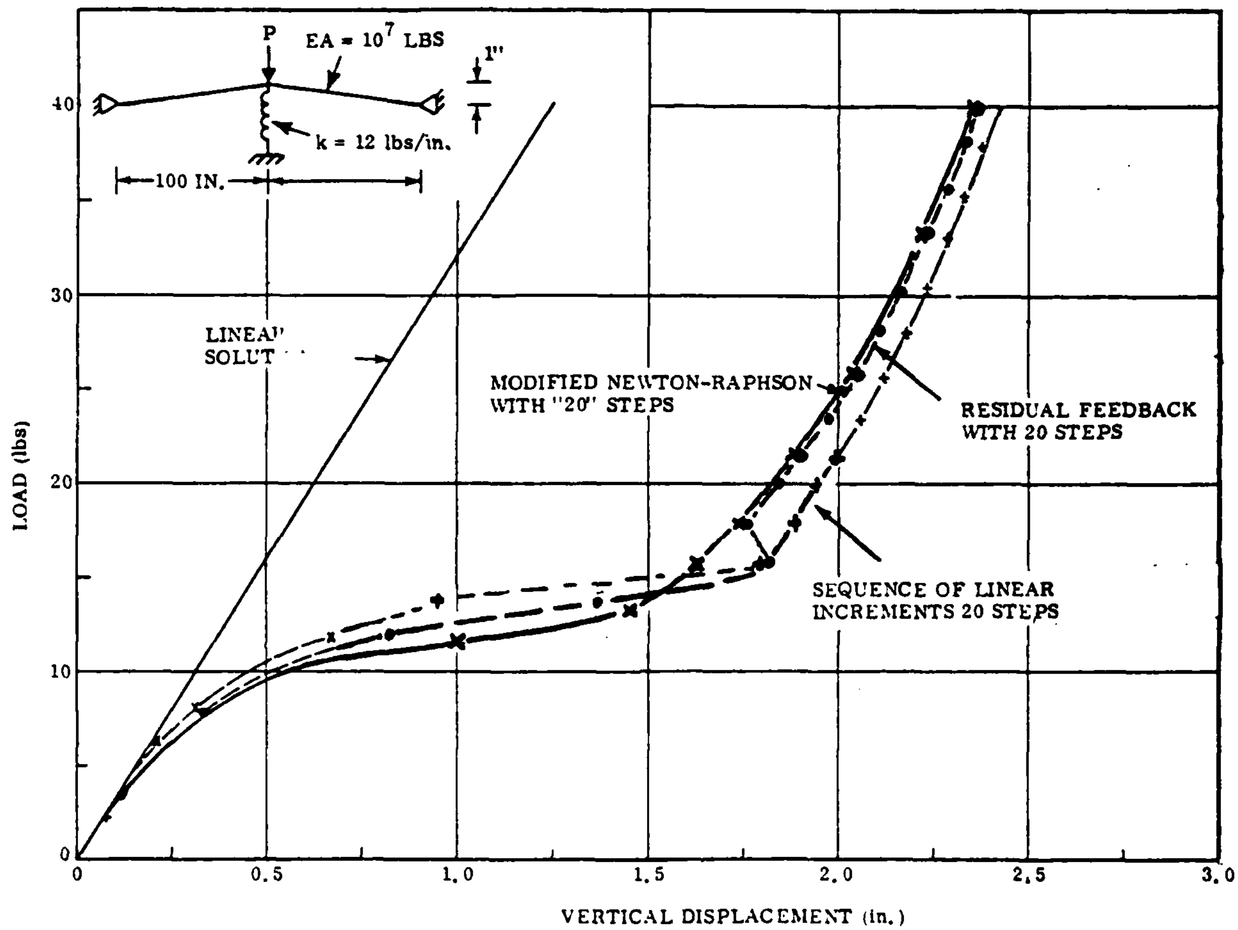
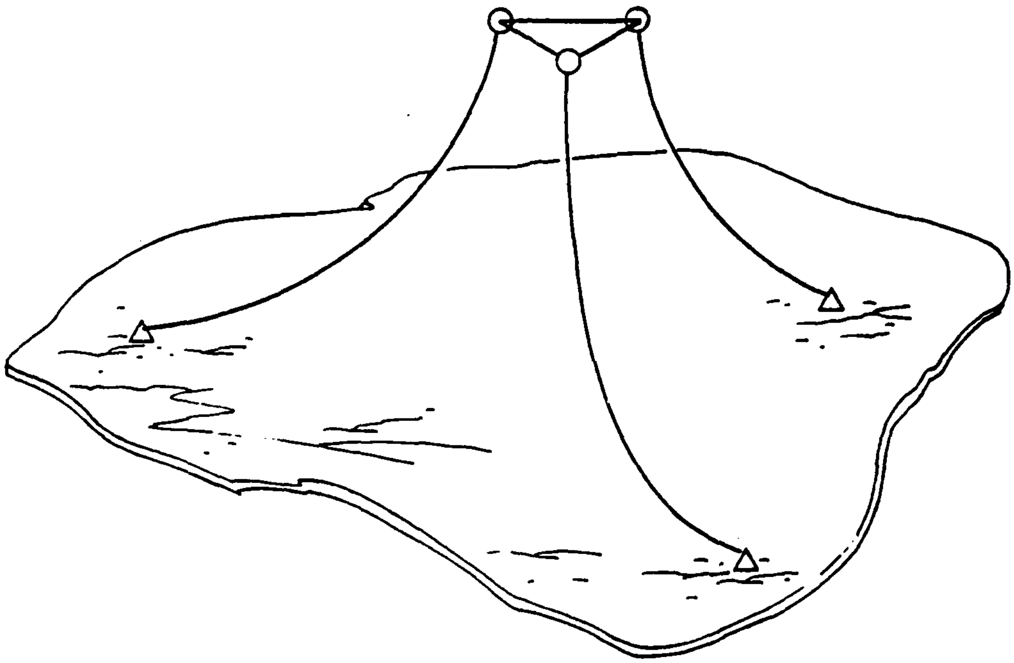


FIGURE 6-1 TWO-BAR TRUSS SNAPTHROUGH RESPONSE

```
         1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890

 TWO BAR TRUSS WITH SPRING    SAMPLE PROBLEM
    4    3    0    0    3    2    0    0    1    0    1
    2    0 386.
    1                                       1         1
    2    -100.      -1.
    3     100.       -1.
    4               -10000.
    1    2    1    1    1
    2    1    3    1    1
    3    1    4    2    1
    1    1 1.                               9
-600.     -6.0002E-5
-500.     -5.0001E-5
-400.     -4.0001E-5
-200.     -2.0000E-5
0.         0.
200.      2.00002E-5
400.      4.00008E-5
500.      5.00013E-5
600.      6.00018E-5
    2    1 1.
120000.    1.
LIVE    20    1    1         0    1    0    0    0    0   -1

    1                -40.
    1
NEW
MNR SOLN  20 STEP ESTIMATE
   -1    2

LIVE    20    1                   1

    1                -40.
    1
NEW
FEEDBACK SOLN   20 STEPS
   -1    2

LIVE    20    1    2              1

    1                -40.
    1
NEW
```

TABLE 6-1 INPUT DATA FOR TWO-BAR TRUSS



WATER DEPTH	2860 ft
DEPTH AT BUOYS	500 ft
DISTANCE BETWEEN ANCHORS	6600 ft
LENGTH OF EACH LEG	4080 ft
LENGTH OF EACH ARM	1000 ft
CABLE DIAM	0.060583 ft (0.727 in.)
CABLE WEIGHT IN SEA WATER	0.31 lb/ft
CABLE EA	1.7735×10^6 lbs
NET BUOYANT FORCE (EACH BUOY)	1745 lbs
BUOY DIAM	5.5833 ft

FIGURE 6-2 THE SEACON II STRUCTURE

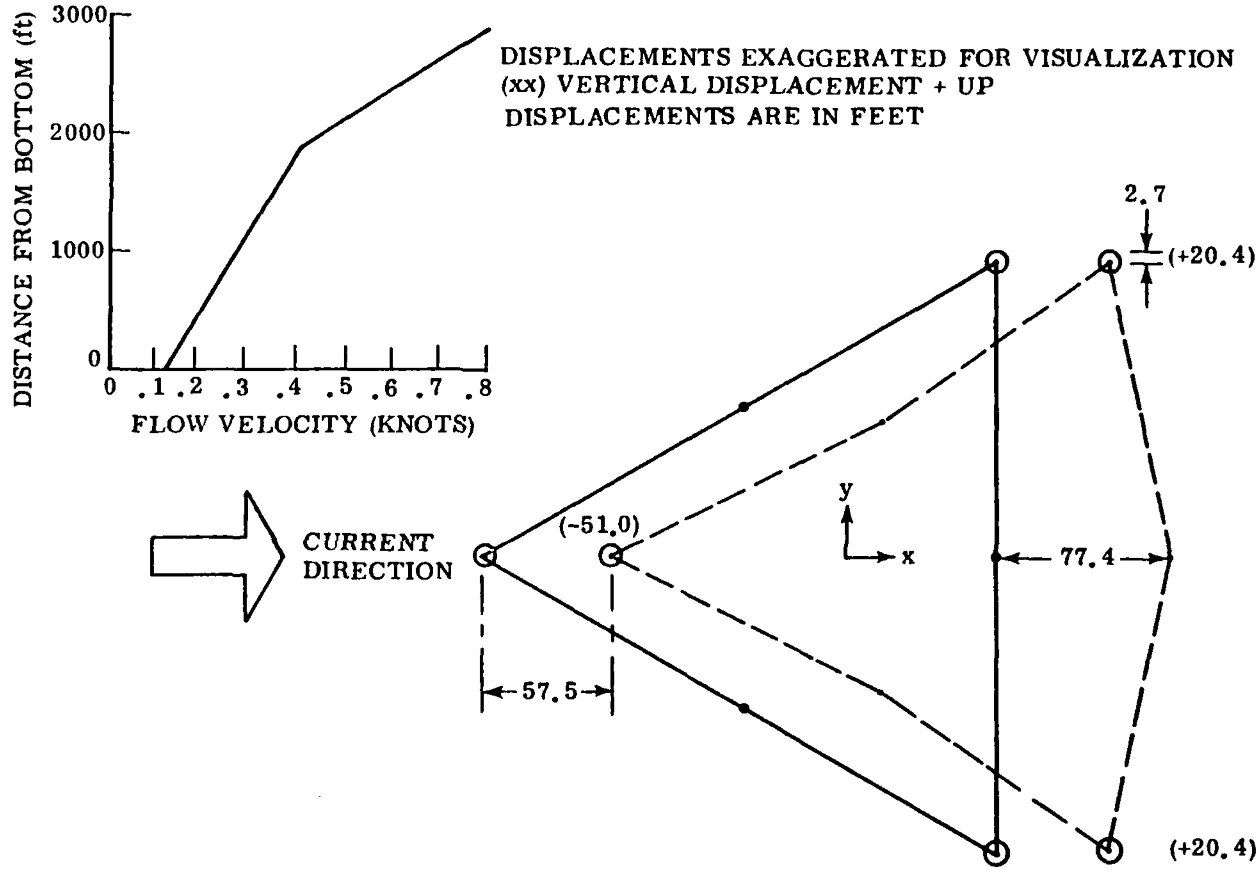


Figure 6-3. Deflection of SEACON II Delta

```
         1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890

SEACON II STATIC LOAD ANALYSIS    UNSTRETCHED LENGTHS
  30    3    0    0   30    1    3    0    1    0    1
  -3    3 32.2       1.77   E-5 64.
   1       288.675              2488.587
   2      -144.338   250.       2488.587
   3      -144.338  -250.       2488.587
   4      -577.35    0.         2488.587
  28    3-3810.5118 0.          0.
   5       288.675   -500.      2566.525
  29    3 1905.2559-3300.       0.
   6       288.675   500.       2566.525
  30    3 1905.2559 3300.       0.
   1    4    7    1                        -1
   9    5    8    1         3
  17    6    9    1         3
  25    5    1    1         3
  26    1    6    1
  27    6    2    1
  28    2    4    1
  29    4    3    1
  30    3    5    1
   1    0 .06058333 .31
1773500.   1.
   4    0 1745.     5.58333333
   5    0 1745.     5.58333333
   6    0 1745.     5.58333333
DEAD   10    1    2    0   10
.0001
DEAD    1    1                                        1              50

LIVE    1    1                              1         1

END

*CUR            SEACON II PROFILE IN Y DIRECTION
      SUBROUTINE CURREN(I,X,N3,V,NFL)
      DIMENSION X(1),V(1)
      VN=1.6873
      DO 200 I=1,N3,3
      V(I+1)=0.
      V(I+2)=0.
      IF(X(I+2).GT.1860.) GO TO 100
      V(I)=VN*(.14+.26*X(I+2)/1860.)
      GO TO 200
  100 V(I)=VN*(.4+.4*(X(I+2)-1860.)/1000.)
  200 CONTINUE
      RETURN
      END
```

TABLE 6-2 INPUT DATA FOR SEACON II STATIC RESPONSE

configuration the buoys are nearly 200 feet below their position in the unstretched (straight line) configuration. This means they must drop almost 10% of their initial height.

The input data listed in Table 6-2 shows a procedure where the dead-loaded configuration was obtained by assuming initial tensions (Method 1 of Section 3.5) and proceeding with a 10 step DEAD solution using the RFB method. This was followed by a MNR correction to that configuration. The current was then applied in a LIVE subanalysis using the MNR method.

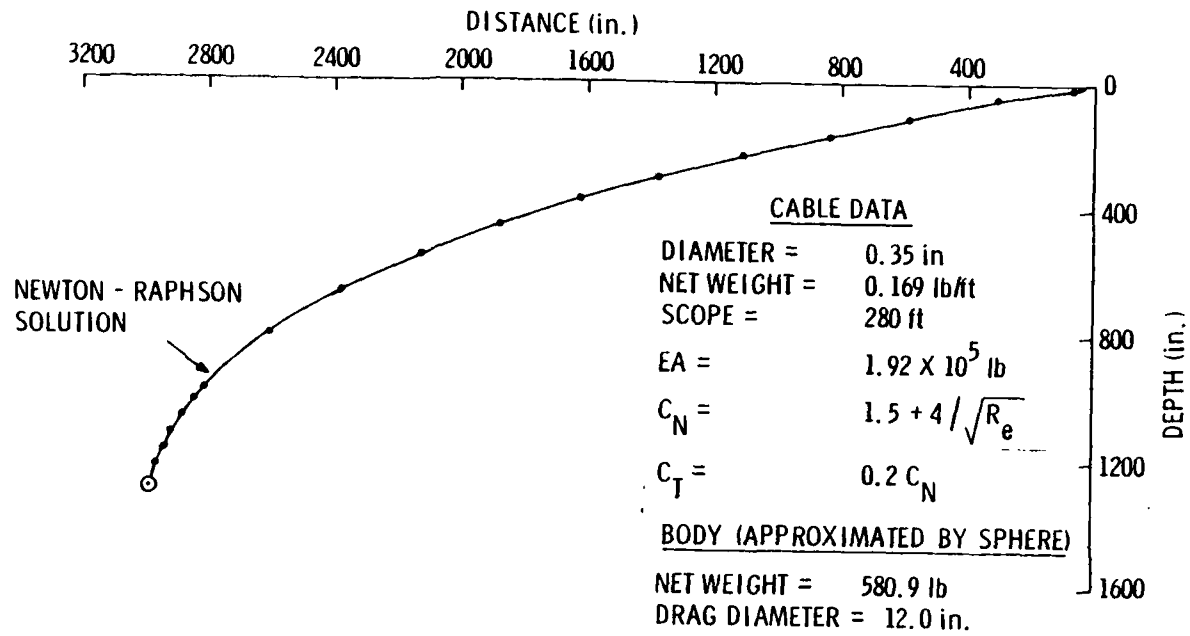
6.3 THE TOWED BODY PROBLEM

Gibbons and Walton [19] report experimental data on the steady-state configuration of a body towed at sea by a single bare cable. Figure 6-4 shows the results of a finite element analysis of the problem. The data shown in the column marked "FLUID LOAD ERROR" represents a solution with the fluid drag load calculated from an erroneous application of Morrison's Equation and the independence principle. The towed body was modeled as an equivalent sphere with the data shown in Figure 6-4.

The dynamic response of the body to a sudden turn is shown in Figure 6-5. The model used in this case had fewer elements than was used for the results in Figure 6-4. The input cards for the dynamic case are presented in Table 6-3. The analysis proceeded from a simple DEAD subanalysis with the line straight down, to a LIVE subanalysis to get the steady-state solution and then to a DYN subanalysis with a dynamic initial condition. Table 6-3 also shows the TVARY subroutine used to produce the course change.

6.4 ANCHOR SUSPENSION DYNAMICS

The response of a system to imposed motion is demonstrated on the system shown in Figure 6-6, with the results shown in Figure 6-7. The input cards are given in Table 6-4. The TVARY subroutine shown in the table produces the sinusoidal motion.



	EXPERIMENT [19]	N-R SOLUTION	FLUID LOAD ERROR
DEPTH OF BODY (in.)	1296	1344	2601
TENSION AT BODY (lb)	590	581	585
ANGLE AT BODY (deg)	80	84	84
TENSION AT SHIP (lb)	659	662	2138
ANGLE AT SHIP (deg)	8	10	46

Figure 6-4. Static Configuration of a Towed Body

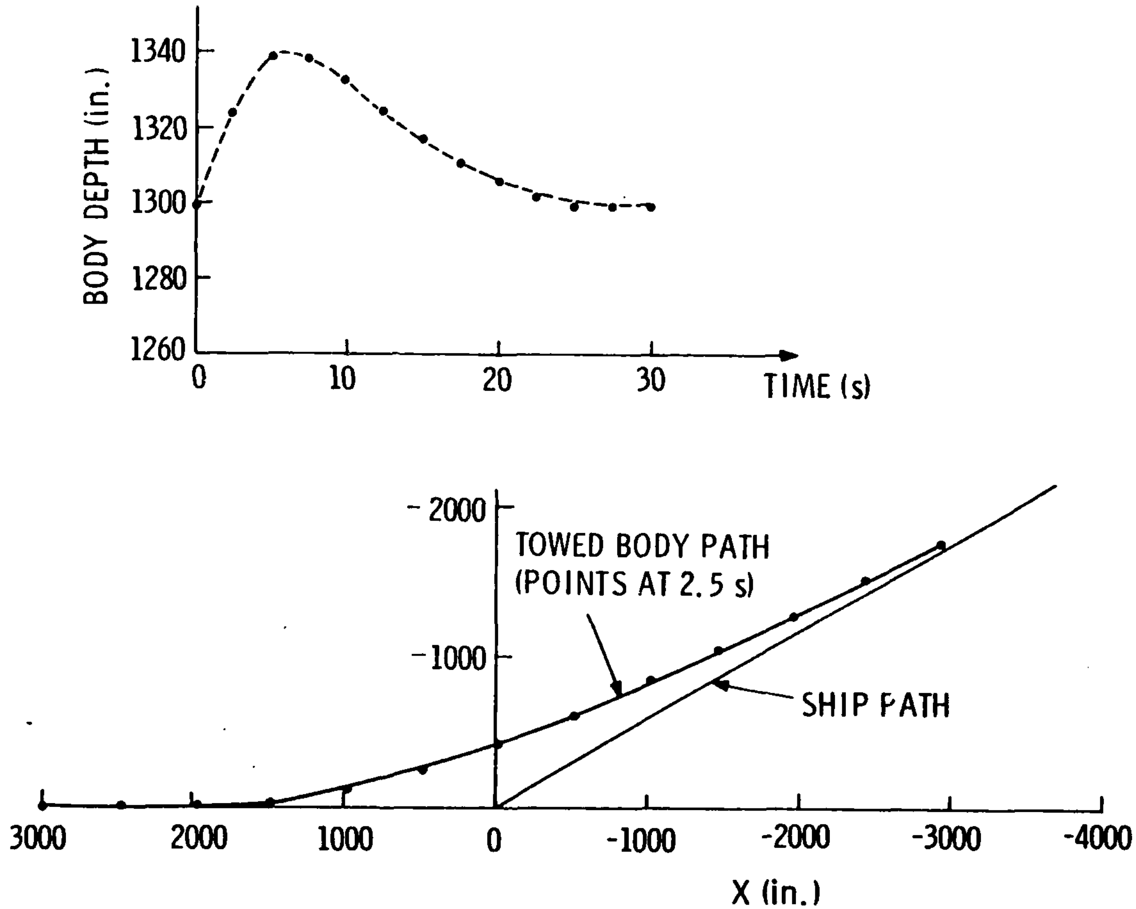
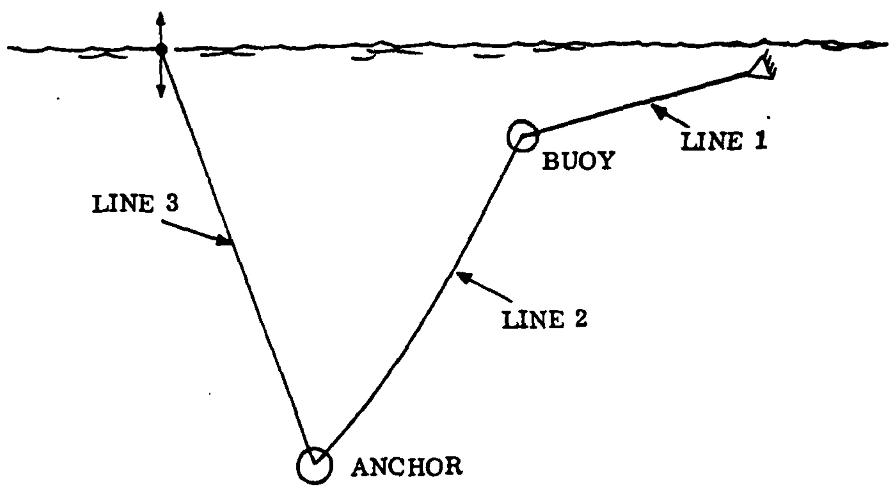


Figure 6-5. Towed Body Response to 30° Turn

```
         1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890

TOWED BODY IN 30 DEGREE TURN
   11    0    1    0   10    1    1    0    1    1    1
    2    1  386.     0.00252     0.037
    1    0 0.        3360.
   11    1
    1    1    2    1
   10   10   11    1
    1    1 .35       .014112                 1
   1.92E07  100.
    1     - 580.9    12.0
DEAD     1    1
.0001
LIVE    10    1    2    0    0    0   -2
212.8
LIVE     1    1    0    0    0    0   -2                  -1
212.8
DYN      0   50    5    0                       1         -1   -1
.002      0.        30.       .5        .08333333
   11         2    1 -212.8       1    1 0.            2    2 -212.8
-212.8
END

*TVARY        TOWED BODY 30 DEG TURN
      SUBROUTINE TVARY(T,F,I)
      GO TO (100,200),I
  100 F=.866
      GO TO 300
  200 F=.5
  300 RETURN
      END
```

TABLE 6-3 INPUT DATA FOR TOWED BODY TURN



BUOY: BUOYANT FORCE 11,200 LBS
DIAMETER 6.0 FT

ANCHOR: *WEIGHT (IN WATER)* 25,000 LBS
DIAMETER 5.0 FT

LINE	UNSTRETCHED LENGTH (ft)	EA (lbs)	WEIGHT IN WATER (lb/ft)	DIAM (ft)
1	4000	7×10^6	0	0.25
2	6500	7×10^6	1.0	0.0917
3	7000	6×10^5	0	0.167

Figure 6-6. Description of Anchor Suspension System

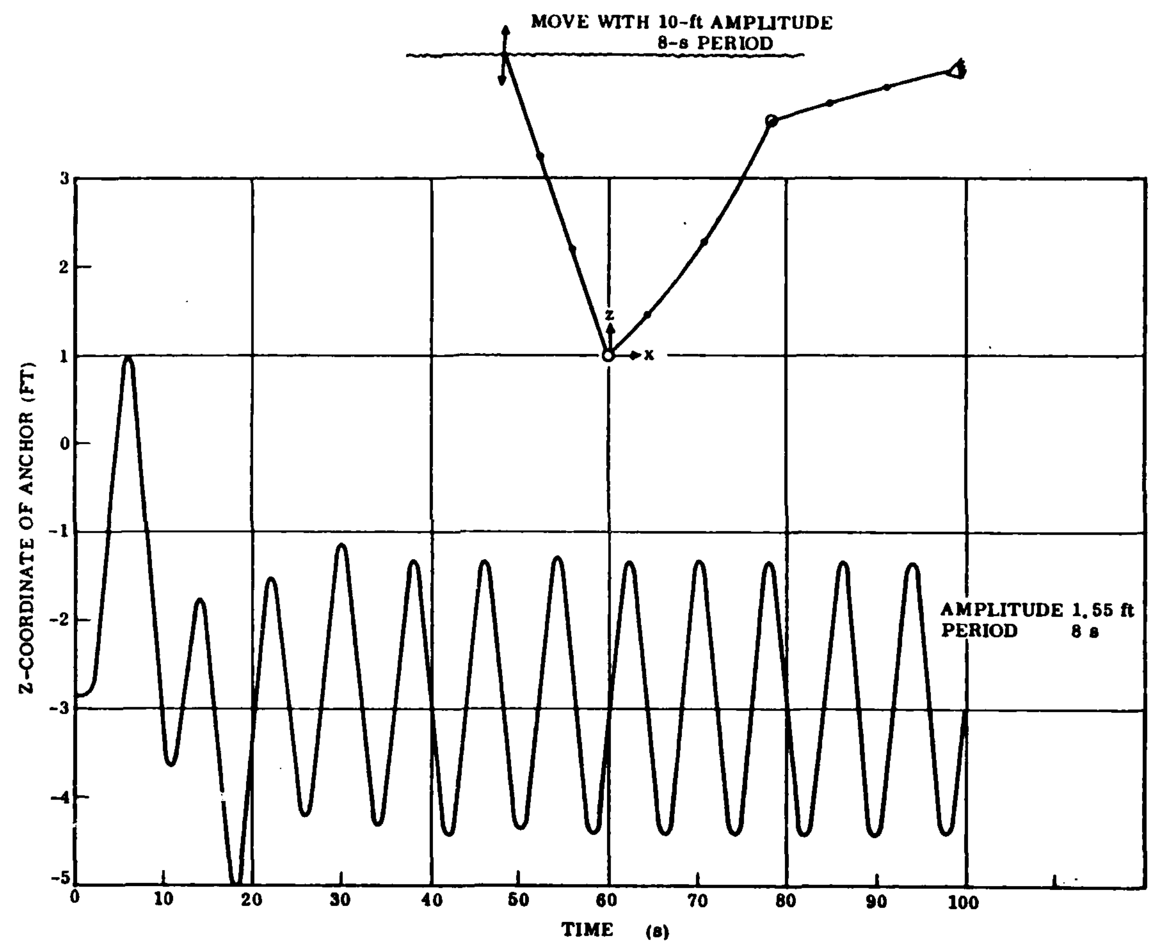


Figure 6-7. Anchor Suspension Response

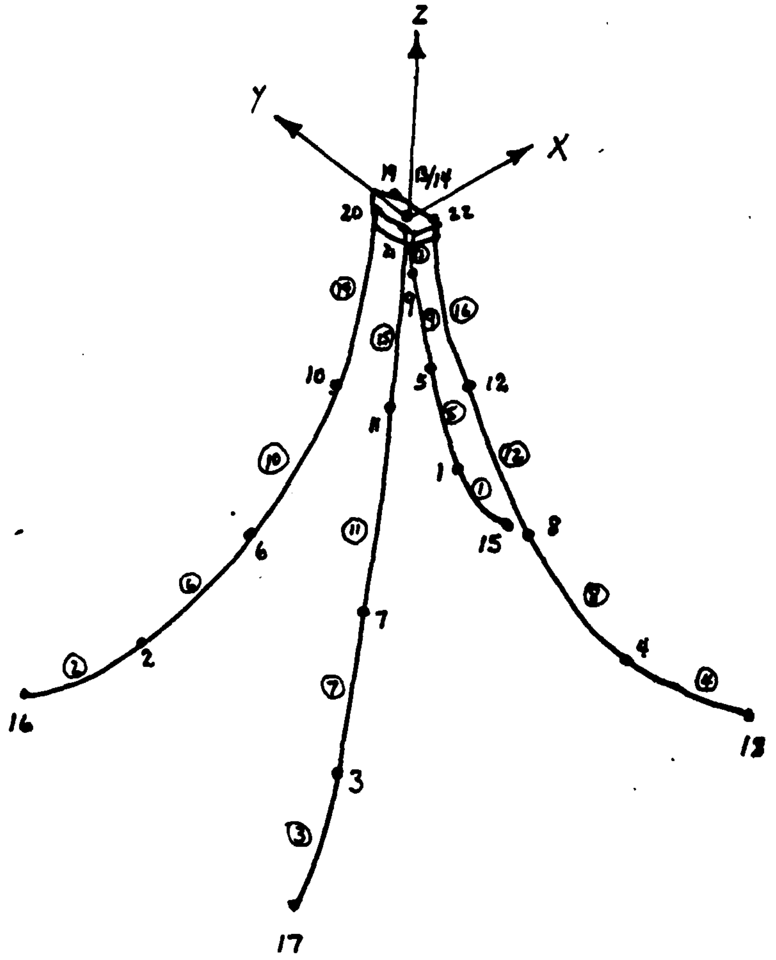
```
         1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890

ANCHOR SUSPENSION DYNAMICS TEST CASE
  10    1    1    0    9    3    2    0    1    1    1    1
  -3    0        32.2  1.77E-5         64.4
   3    03616.     0.            5380.
   4    02049.     0.            2586.
   5    0807.      0.            891.
   6    00.        0.            0.
   9    1-2308.    0.            6851.
  10    07500.      0.           6350.
   2    3   10   -1
   1   10    1    1              6460.
   2    1    2    1              6460.
   3    2    3    1              6460.
   4    3    4    2              12904.5
   5    4    5    2              10671.5
   6    5    6    2              9390.4
   7    6    7    3              19667.3
   8    7    8    3              19667.3
   9    8    9    3              19667.3
   1    00.25      0.            1.0                 1
7.     E6   1.
   2    00.0917     1.0          1.0                 1
7.     E6   1.
   3    00.167     0.            1.0                 1
6.     E5   1.
   3       11200.       6.
   6      -25000.        5.
DEAD    1    1

DYN     0   10    5    0                                        -1

  .1        .1         100.      .5        .08333333
   9         1    2 10.            1    1          0.     1    1   10.
END
```

```
      SUBROUTINE TVARY(T,F,I)
      F=0.
      PER=8.
      IF(I.EQ.1) F=SIN(6.2831853*T/PER)
      RETURN
      END
```

TABLE 6-4 INPUT DATA FOR ANCHOR SUSPENSION DYNAMICS

6.5 STATIC EXCURSION OF DD-692 IN A FOUR POINT MOOR

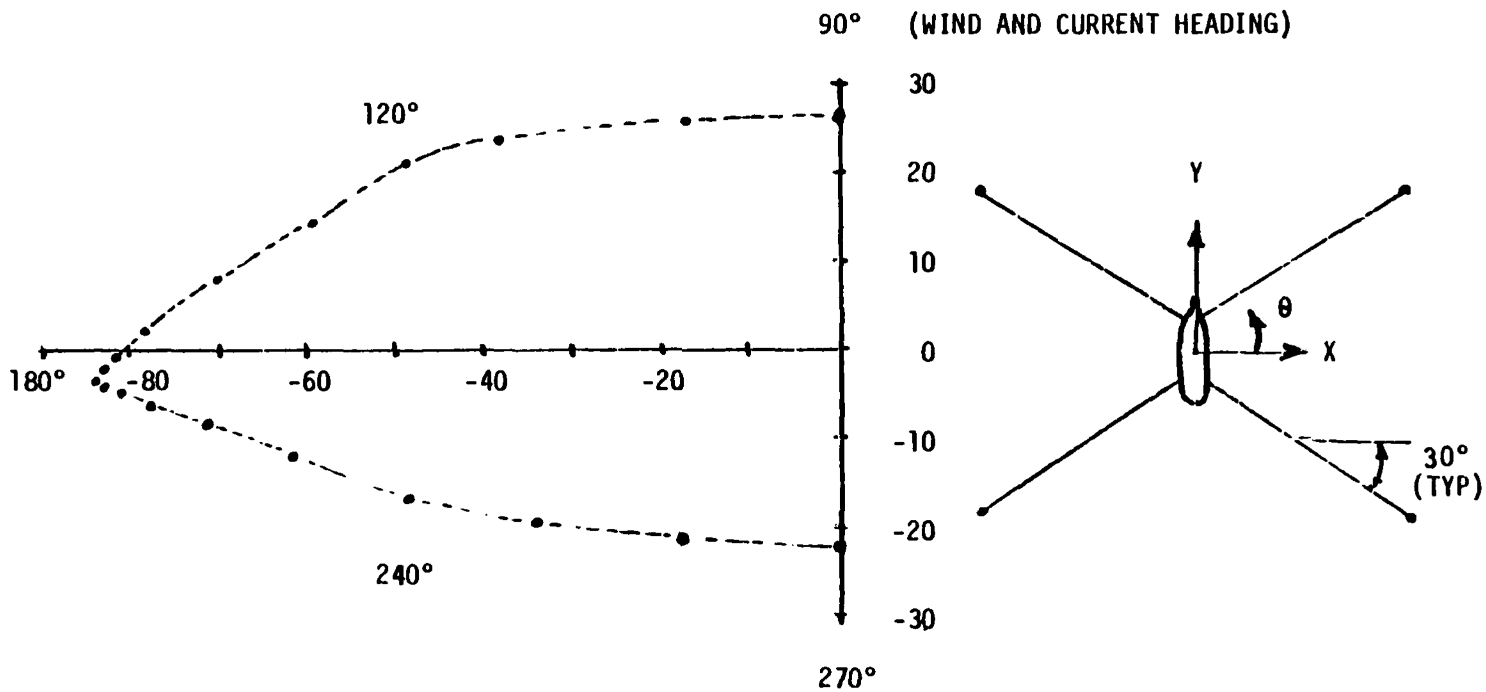
A finite element model of the DD-692 ship in a four point slack moor is shown in Figure 6-8. The position of the ship relative to its quiescent position is plotted in Figure 6-9. The loading was a wind of 30 knots and a surface current of 2 knots. They were assumed to have coincident headings and were applied initially as beam loading and varied incrementally to head loading on increments of ten degrees. The quiescent state was recovered with a restart and loading was varied from beam to following seas in ten degree increments. The input cards are presented in Table 6-5.



| - Node Number

① - Element Number

FIGURE 6-8 MODEL OF DD-692 IN FOUR POINT MOOR



WIND VELOCITY = 30 knots

CURRENT = 2 Knots

FIGURE 6-9 DD-692 EXCURSION ENVELOPE

```
         1         2         3         4         5         6         7
12345678901234567890123456789012345678901234567890123456789012345678901234567890

DD-692 IN FOUR POINT MOOR
   22    4    0    4   16    1    0    1    1    0    1    4    1
   -3    0  32.17    1.77  E-5   64.     1.68  E-4  .0765                   -1000.
DD962 FROM DM-26
LB         TON        FEET        KNOTS
377.        1400.     10100.      369.        41.        10.62       76300.    161.
    1    13 73.8         125.
0.         30.        60.         90.         120.       150.        180.      210.
240.       270.       300.        330.        360.
10.
9.         47.         -46.
6.          76.        -53.
5.         86.        -14.
-1.5       80.         9.
-11.        47.        9.
-10.        0.         -1.
-11.       -50.         -6.
-1.5       -80.         -6.
5.         -88.        25.
6.         -77.         52.
9.          -41.          45.
10.
    3    19 25.       2.          4.          6.
0.         10.        20.         30.         40.        50.         60.       70.
80.        90.        100.        110.        128.        130.       140.      150.
160.       170.       180.
1.7
1.7         3.         -100.
1.7          7.       -400.
1.7        11.        -700.
1.6        16.         -1000.
1.4        20.5        -1000.
1.3         25.5       -800.
1.2         28.        -600.
.8          29.        -400.
.6          30.         -200.
.4          29.
0.          28.        150.
-.8           25.      200.
-1.7        20.         180.
```

TABLE 6-5   INPUT DATA FOR DD-692 EXCURSION

-2.	14.5	110.
-2.3	10.	80.
-2.4	6.5	50.
-2.5	3.	10.
-2.5		
5.		
5.	11.	-1000.
5.	23.	-2000.
5.	42.	-2800.
4.8	60.	-3400.
4.4	78.	-3300.
4.	95.	-2900.
3.5	108.	-2400.
2.5	112.	-1900.
2.	115.	-1300.
1.	112.	-600.
0.	108.	150.
-2.	95.	600.
-4.	78.	600.
-6.	60.	400.
-7.5	42.	250.
-8.	23.	200.
-8.	11.	100.
-8.		
12.6		
12.6	27.	-900.
12.6	60.	-3100.
12.6	99.	-6600.
11.5	142.	-8400.
10.5	192.	-8100.
9.	240.	-6900.
8.	280.	-5900.
6.	304.	-4600.
4.	310.	-3000.
2.	303.	-1400.
0.	278.	
-3.	238.	1000.
-7.	186.	1200.
-9.	132.	1000.
-11.	88.	700.
-13.4	52.	400.
-13.4	22.	100.
-13.4		

Revised JULY 1978

TABLE 6-5 (CONT)

```
   13
   14       0.           0.          270.                          DEGREE
   15       951.542     693.6      -1000.
   16      -951.542     693.6      -1000.
   17      -961.542    -693.6      -1000.
   18       961.542    -693.6      -1000.
   19       10.          150.                     -13
   20      -10.          150.                     -13
   21      -20.         -150.                     -13
   22       20.         -150.                     -13
    3   15   19    4     0     1     1     35.        25000.
    3   16   20    4     0     2     1     35.        25000.
    3   17   21    4     0     3     1     35.        25000.
    3   18   22    4     0     4     1     35.        25000.
    1   15    1    1    -1
    5    1    5    1    -1
   13    9   19    1    -1
   16   12   22    1    -1
    1    0  .167        35.
3.      E7   1.
   13    1

1.           2240.       1.          1.6878
DEAD     1     1     0     1                                  -1

LIVE    20     1     0     1                          6              30

50.634     180.        3.3756    180.       -18.      90.
NEW
GET EXCURSION LIMIT BETWEEN 190 AND 270 DEGREES
    0    1

LIVE    20     1     0     1                          6              30

50.634     190.        3.3756    190.       10.       270.
END
```

TABLE 6-5 (CONT)

7.0 REFERENCES

1. Dunder, V.F., Robl, F.J., "NLIN:Nonlinear Static and Dynamic Analysis of Submerged Cable Structures," Bechtel Corp., San Francisco, CA, 22 Novmeber 1973.

2. Webster, R.L., "An Application of the Finite Element Method to the Determination of Nonlinear Static and Dynamic Responses of Underwater Cable Structures," PhD Thesis, Cornell University, Ithaca, NY, Jan. 1976. Also available as General Electric Co. Report TIS R76EMH2, January 1976.

3. Oden, J.T., FINITE ELEMENTS OF NONLINEAR CONTINUA, McGraw-Hill, New York, 1972.

4. Meyers, W.G., Sheridan, D.J., Salvesen, N., "Manual-NSRDC Ship-Motion and Sea-Load Computer Program," David Taylor Naval Ship Research and Development Center, Bethesda, MD, Report 3376, February 1975.

5. Webster, R.L., "SEADYN/DSSM Program Maintenance Manual," The General Electric Company, Electronic Systems Division, Syracuse, NY, Contract N62477-76-C-0002, Report DSSM-3, November 1976.

6. Webster, R.L., "SEADYN/DSSM Program Acceptance Report," The General Electric Company, Electronic Systems Division, Syracuse, NY, Contract N62477-76-C-0002, Report DSSM-4, November 1976.

7. Choo, Y.I., Casarella, M.J., "Hydrodynamic Resistance of Towed Cables," J. HYDRONAUTICS, V5 n4, Oct. 71, p 126-131.

8. Anon., "Design Manual:Harbor and Coastal Facilities," Dept. of the Navy, Naval Facilities Engineering Command, Wash., DC, NAVFAC DM-26, July 1968.

9. Webster, R.L., "DESMOOR:Deep Sea Moor Static Design Computer Program (User's Manual)," The General Electric Company, Electronic Systems Division, Syracuse, NY Contract N62477-76-C-0002, Report DSSM-1, Aug. 1976.

10. Garrison, C.J., "Hydrodynamics of Large Objects in the Sea Part II: Motion of Free-Floating Bodies," J. HYDRONAUTICS, V9 n2, April 1975, p 58-63.

11. Patton, K.T., "The Response of Cable-Moored Axisymmetric Buoys to Ocean Wave Excitation," PhD Thesis, Brown Univeristy, available as Naval Underwater Systems Center Tech Report 4331, June 1972.

12. Kim, W.D., "On the Harmonic Oscillations of a Rigid Body on a Free Surface," J. OF FLUID MECHANICS, V 21, Part 3, 1965, p 427-451.

13. Kim, W.D., "On a Free-Floating Ship in Waves," J. OF SHIP RESEARCH, Sept. 1966, p 182-200.

14. Newmark, N.M., "A Method of Computation for Structural Dynamics," J. OF THE ENGINEERING MECHANICS DIV., ASCE, V 85, n EM-3, paper 2094, July 1959, p 67-94.

15. Crandall, S.H., RANDOM VIBRATION, MIT Press Cambridge, MA, 1963.

16. Felippa, C.A., "Finite Element Analysis of Three-Dimensional Cable Structures," Proc. of International Conf. on Computational Methods in Nonlinear Mechanics, Austin, Texas, Sept. 23-24, 1974, p 311-324.

17. Stricklin, J.A., et al, "Geometrically Nonlinear Structural Analysis by Direct Stiffness Method," J. OF THE STRUCTURAL DIV., ASCE, V-97, n ST9, paper 8392, Sept. 1971, p 2299-2314.

18. Kretchmer, T.R., et al, "SEACON II:An Instrumented Tri-Moor for Evaluating Cable Structure Design Methods," Paper No. OTC 2365 presented at the Seventh Annual Offshore Technology Conference, Houston, Texas, May 5-8, 1975.

19. Gibbons, T., Walton, C.O., "Evaluation of Two Methods for Predicting Towline Tensions and Configurations of a Towed Body System Using Bare Cable," David Taylor Model Basin, Washington, DC, Report No. 2313, December 1966 (AD-651543).

APPENDIX A

LOGIC OVERVIEW OF THE SEADYN/DSSM PROGRAM

The SEADYN/DSSM Program consists of a simple main program and a set of more than 50 subroutines. The main program simply establishes the size of unlabeled COMMON and calls the driving routine (SEADYN) which controls the subdivision of unlabeled common into arrays which are sized to meet the requirements of the specific problem being analyzed. The actual execution of the various options of the program are controlled from the MANIPR subroutine which is called by SEADYN. The subanalyses were developed essentially in modular form with the majority of the interfacing done through MANIPR.

Specific information about each of the subroutines and macro-flow charts of each of the subanalyses are provided in the Program Maintenance Manual [5]. A macro-flow chart of the overall analysis flow is presented in Figure A-1. The first block corresponds to the main program. The next three levels are contained in the SEADYN subroutine. The remainder represents the MANIPR subroutine and subroutines it calls.

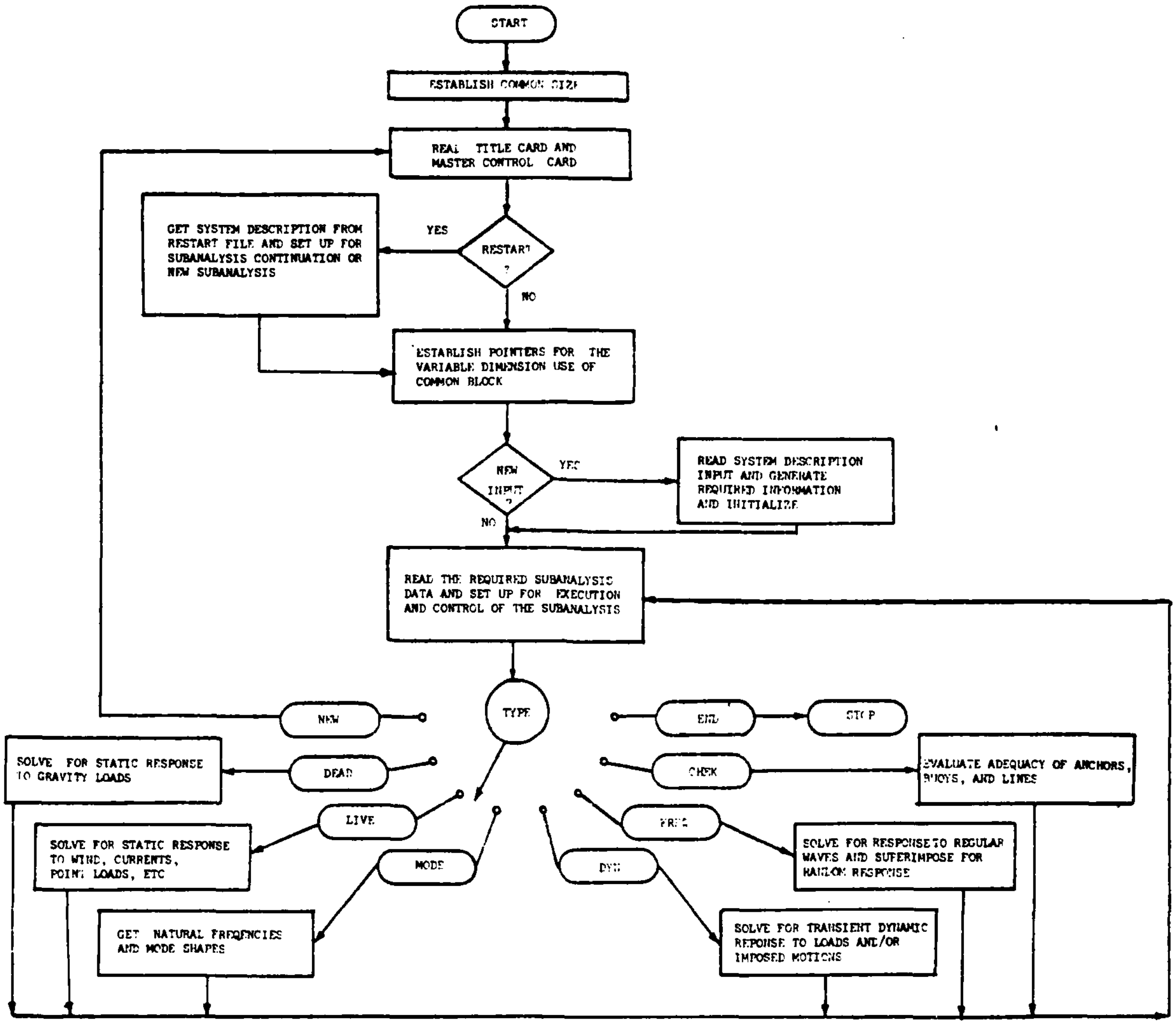


FIGURE A-1 MACRO FLOW CHART OF SEADYN/DSSM

APPENDIX B

SHIP's LOADING FUNCTIONS

This Appendix is an excerpt from the DESMOOR Program user's manual [9]. It describes the tabular and analytical approaches to obtaining static loads on a ship subjected to winds and surface currents. Identical procedures are used in SEADYN/DSSM and DESMOOR insofar as the ships loads are concerned. The ship loading file generated by either one of the programs can be used by the other.

The references for this Appendix are:

3. Anon., "Design Manual:Harbor and Coastal Facilities," Dept. of Navy, Naval Facilities Engineering Command, Washington, DC, NAVFAC DM-26, July 1968.

4. Hughes, G., "The Air Resistance of Ship's Hulls with Various Types and Distributions of Superstructures," IESS, 1932.

5. Rossell, H.E. PRINCIPLES OF NAVAL ARCHITECTURE, SNAME, 1939.

6. Altman, R., "Forces on Ships Moored in Protected Waters," HYDRONAUTICS, Inc., Tech Rept. 7096-1, July 1971.

The external loads applied to the mooring system are all assumed to be applied through the ship. Three sources of loading are considered: wind loads, surface currents, and point loads representative of working loads. The point loads are specified by giving the coordinates of the point where the loading is applied and then giving the components of the lateral load and the yaw moment. It is assumed that the point loads do not change their magnitude or global directions as the ship moves to a new position. Specification of the wind and current loadings is somewhat more complicated. The DESMOOR program provides two approaches to defining these loads. The first is in the form of loading tables which give load coefficients versus ship's heading relative to the flow. The second approach uses approximate analytical expressions.

The tabular approach is based on the procedures given in NAVFAC Design Manual 26 (DM-26) [3]. The DM-26 approach utilizes experimental curves for the forces and moments for various headings of wind and current for a set of "representative" vessels. Similarity scaling is then applied to get loading values for ships other than the test models.

The DM-26 procedure begins with a set of load measurements obtained from subscale tests on a representative ship's model. The measurements give values for the lateral and longitudinal forces and yaw moment versus flow heading. These measurements represent the combined effects of such phenomena as profile and friction drag, lift induced side forces, and shifts in the center of pressure. Tables of these measurements can be specified as input to the DESMOOR program or a special ship loading file can be generated and saved for use with both the DESMOOR and SEADYN programs.

Given the headings of wind and surface current relative to the ship, the loading coefficients are obtained by linear interpolation in the tables. In the event that there are tables provided for more than one velocity, the table for the velocity nearest the one specified in the analysis will be used. This is determined by comparing the squares of the velocity ratios.

After the load coefficients are obtained from the tables they must be scaled to account for differences in the conditions modeled in the test and those being analyzed. The scaling accounts for differences in flow velocity, water depth and ship geometry.

The formulas for adjusting for the effects noted above are given in DM-26, and they are restated here for completeness.

<u>WIND</u>

$$F_s = C_f V^2 F_{ms} \; A_s / A_{ts} \qquad (2\text{-}20)$$

$$F_e = C_f V^2 F_{me} \; A_e / A_{te} \qquad (2\text{-}21)$$

$$M_w = C_m V^2 M_m A_s L / A_{ts} L_t \qquad (2\text{-}22)$$

where

F_s = lateral force on ship

F_e = longitudinal force on ship

M_w = yawing moment on ship

F_{ms} = lateral force on model

F_{me} = longitudinal force on model

M_m = yawing moment on model

V = wind velocity

A_s = side-projected areas above the water line of ship being analyzed

A_{ts} = side-projected area above the water line of modeled ship

A_e = end-projected area above the water line of ship being analyzed

A_{te} = end-projected area above the water line of modeled ship

L = Length of ship being analyzed

L_t = Length of modeled ship

$$C_f = \frac{S^2}{V_T^{\,2}} \tag{2.23}$$

$$C_m = \frac{S^3}{V_T^{\,2}} \tag{2.24}$$

S = linear scale of the model

V_T = wind velocity used in model test

<u>CURRENT</u>

$$h_2 = h_1\, L_{W2}/L_{W1} \tag{2.25}$$

$$V_1 = V_2 \sqrt{L_{W1}/L_{W2}} \tag{2.26}$$

$$F_2 = F_1\, \Delta_2/\Delta_1 \tag{2.27}$$

$$M_2 = M_1\, \Delta_2 L_{W2}/\Delta_1 L_{W1} \tag{2.28}$$

where

h = depth of water
V = velocity of current
L_W = water line length of vessel
F = lateral or longitudinal resisting force
M = yaw resisting moment
Δ = displacement

Subscript 1 denotes the vessel for which the test was made, and subscript 2 denotes the vessel being analyzed.

When the velocity from Equation (2.26) does not correspond to one of the tables given for the model test then the forces and moments will be selected from the tables corresponding to the velocity nearest the value of V_1 in Equation (2.26). It will then be necessary to adjust the values by the square of the ratio of the V_1 velocity and the velocity represented in the tables, V_{t1}.

It is quite likely that the depth at the proposed mooring site will not be the same as that obtained for h_2 in Equation (2.25). In that event, a correction for depth is required. DM-26 suggests that the correction be made assuming an inverse relationship with the side resistances at the two depths in question. The curves given in Graph 124 (EC-2) of DM-26 are used along with Equation (2.25) for this purpose. The data is given in tabular form and the side resistances are obtained by logarithmic interpolation. The resistance for a depth greater than that in the table will be the last value in the table.

The adjustments for current velocity and depth are summarized by the following equations:

$$F'_{s2} = f_h \frac{V_1^2}{V_{t1}^2} F_{s2} \tag{2.29}$$

$$F'_{e2} = f_h \frac{\Delta_2}{\Delta_1} \frac{V_1^2}{V_{t1}^2} \left(F_{e1} - \frac{1}{2} \rho_1 C_{p1} A_1 V_{t1}^2 \right) + \frac{1}{2} \rho_2 C_{p2} A_2 V_2^2 \tag{2.30}$$

$$M'_2 = f_h \frac{V_1^2}{V_{t1}^2} M_2 \tag{2.31}$$

where

f_h = the depth scaling factor

V_{t1} = the velocity at which the test data was obtained

A = the propeller projected area

C_p = the propeller drag coefficient

The primes indicate the value adjusted to the desired conditions for the mooring site. Equation (2.30) reflects the adjustment in the longitudinal force recommended by DM-26 with the assumption that $\frac{1}{2} \rho C_p = 2.88$ with A in ft^2 and V in knots. Assuming the specific weight of sea water is 64 lb/ft^3 and the acceleration due to gravity is 32.2 ft/sec^2 then $C_p = 1.00$. The form using $\frac{1}{2} \rho C_p$ rather than 2.88 is required to make the procedure dimensionally independent.[2]

The approximate analytical expressions for ship's loading are based primarily on the work of Hughes [4] and standard naval architectural formulas [5]. The wind loading is given by

$$F = K \rho_a V^2 (A_s \sin^2\theta + A_e \cos^2\theta) \cos(\alpha-\theta) \tag{2-32}$$

where

K = constant, 0.6

F = resultant wind force

ρ_a = density of air

V = wind velocity

θ = wind heading relative to the bow

α = heading of the resultant wind force relative to the bow

The heading of the resultant force, α, is approximated as a function of θ in a 7^{th} order polynomial as follows:

$$\begin{aligned} \alpha = {} & 0.0715608 + 7.954381\theta - 0.325456\theta^2 \\ & + 0.0073131\theta^3 - 9.3966 \times 10^{-5}\theta^4 \\ & + 6.85008 \times 10^{-7}\theta^5 - 2.6323 \times 10^{-9}\theta^6 \\ & + 4.1453 \times 10^{-12}\theta^7 \end{aligned} \tag{2.33}$$

In Equation (2.33) both θ and α are measured in degrees.

The distance between the ship forward perpendicular and the center of wind pressure, X_{cp}, can be approximated as a polynomial function of the wind direction, θ. This relationship is

$$\begin{aligned} \frac{X_{cp}}{L} = {} & 0.2004112 + 0.0048641\theta - 4.52442 \times 10^{-5}\theta^2 \\ & + 5.45736 \times 10^{-7}\theta^3 - 3.78789 \times 10^{-9}\theta^4 \\ & + 1.02881 \times 10^{-11}\theta^5 \end{aligned} \tag{2.34}$$

Here, as above, θ is measured in degrees. The yawing moment due to wind is then approximated by

$$M_W = FL \sin \alpha \left(\frac{1}{2} - \frac{X_{cp}}{L}\right) \quad (2.35)$$

Analytical expressions for the resistances from current effects utilize the approach presented by Altman [6]. These expressions are summarized below:

$$F_s = F_{s\infty} \left(1. + \frac{10}{(h/H)^2 - 1.}\right) \quad (2.36)$$

$$F_{s\infty} = 0.215\ \rho_w V^2\ L_w\ H \sin \theta \quad (2.37)$$

$$F_e = \frac{1}{2} \rho_w V^2 \left(S_w C_R + AC_p\right) \cos \theta \quad (2.38)$$

$$S_w = C_s \sqrt{\nabla L_W} \quad (2.39)$$

where

∇ = displaced volume

C_s = wetted surface coefficient, input with ship description

C_R = hull resistance coefficient, input with ship description or calculated as $C_r + C_f + 0.0005$ (2.40)

C_r = residuary resistance coefficient

C_f = frictional resistance coefficient, $= \dfrac{0.456}{(\log_{10} R_e)^{2.58}} - \dfrac{1700}{R_e}$ (2.41)

R_e = Reynolds number for the hull

$$M = F_s\ L_{CP} \quad (2.42)$$

L_{CP} = distance from midships to hull center of pressure

$$L_{CP} = L\ [\overline{L}_{90} + 0.00226\ (\theta - 90°)]\ \text{for } 0° \leq \theta \leq 180°$$

$$L_{CP} = L\ [\overline{L}_{90} + 0.00226\ (\theta - 270°)]\ \text{for } 180° \leq \theta \leq 360° \quad (2.43)$$

$\bar{L}_{90}$ = ratio of distance to center of pressure at $\theta = 90°$ to the distance to the center of hull side area

Various of these terms require further discussion. The hull resistance coefficient, C_R, represents the sum of various coefficients for different sources of hull resistance. This coefficient may be input or calculated in the computer program. When no input is given for C_R it will be calculated as the sum of a residuary resistance coefficient, a frictional resistance coefficient, and a fouling/surface effect coefficient. The fouling/surface effect coefficient will be given an arbitrary value of 0.0005. The frictional coefficient will be calculated from Equation (2.41) and the residuary coefficient will be obtained from linear interpolation in a digitized form of Figure 38 of the Altman report [6]. This method of obtaining C_r is limited to low flow velocities since wave-making resistances are ignored.

The longitudinal location of the center of pressure for a hull skewed with respect to the flow is estimated by Equations (2.43). This requires an estimate of the ratio of the distance to the center of pressure and the center of area for beam flow, $\bar{L}_{90}$. This factor will be estimated by linear interpolation between the values for the ships DD-692 and EC-2 using the block coefficient as a reference. Altman gives the values for $\bar{L}_{90}$ for the DD-692 and EC-2 as 0.056 and -0.138, respectively. (Negative means aft of midships.)

It should be emphasized that these analytical expressions are to be viewed as a convenient alternative to the DM-26 experimental curve procedure. They are not represented as highly accurate, and it remains to be demonstrated that they are capable of giving reliable approximations of the ships loading.

APPENDIX C

DESCRIPTIONS OF THE SHIP LOAD FILE AND COMPONENT INVENTORY DATA

This Appendix deals with the special storage requirements of the Ship Load File (logical unit 10) and the arrays for the mooring component inventories.

The Ship Load File can be setup and/or used by either the DESMOOR or the SEADYN/DSSM Program. The file contains one logical record for each ship cataloged on the file and it is written in a binary form with the following FORTRAN statement:

```
WRITE(10)NWIND,NTHETW,WNDVEL,WNDHED,WNDCOE,SCALE,NCRNT,NTHETC,CURVEL,CURHED,
CURCOE,TDEPTH,TBLOCK,TSLT,TSAE,TSAS,TSWL,TSB,TSD,TSDSP,TSAP,SHCAP,WLBL,CLBL,LLBL,VLBL
```

A number of the items in the list are arrays and they are written in their entirety using the implied DO-LOOP feature of FORTRAN I-O statements. A description of each item including the dimensions of the arrays is given below.

VARIABLE	DESCRIPTION
NWIND	No. of wind velocity tables
NTHETW	No. of headings in each wind table
WNDVEL(5)	Array of wind velocities
WNDHED(20)	Array of wind headings
WNDCOE(20,3,5)	Array of wind load coefficients giving values for up to 20 headings for end force, side force and yaw moment for up to 5 wind velocities.
SCALE	Scale for wind load tests (A means 1/Ath scale)
NCRNT	No. of current velocity tables
NTHETC	No. of headings in each current table
CURVEL(5)	Array of current velocities
CURHED(20)	Array of current headings
CURCOE(20,3,5)	Array of current load coefficients giving values for up to 20 headings for end force, side force and yaw moment for up to 5 current velocities.

VARIABLE	DESCRIPTION
TDEPTH	Water depth for test
TBLOCK	The ship's block coefficient
TSLT	Total ship length
TSAE	End projected wind area
TSAS	Side projected wind area
TSWL	Water line length
TSB	Beam at mid-ships
TSD	Draft at mid-ships
TSDSP	Volume displacement
TSAP	Propeller projected area
SHPCAP(12)	Title of 12 six-character Hollerith words
WLBL	Wind force label, six-character Hollerith word
CLBL	Current force label, six-character Hollerith word
LLBL	Length label, six-character Hollerith word
VLBL	Velocity label, six-character Hollerith word

The mooring component inventories are contained in arrays which are generated by DATA statements in the COMPDAT subroutine. The data is stored in labeled COMMON as follows:

```
COMMON/COMPNT/ ATYPE(3,6),ANCTAB(5,16,6),NANCR(6),BTYPE(3,2),BUOTAB(7,6,2),
NBUOY(2),HTYPE(3,4),HAWTAB(2,23,4),HAWSIZ(23),NHAWS(4),CHAIN(31,3),NCHN,
HLDFAC(6)
```

VARIABLE	DESCRIPTION
ATYPE	Label for each of 6 anchor types. Each label is 3 six-character Hollerith words.
ANCTAB	Storage for anchor data for up to 6 anchor types (3rd dimension). The array allows up to 16 anchors of each type, listed in order of increasing weight. Five items are given for each anchor.

WORD	CONTENTS
1	Anchor weight
2-4	Hollerith labels for federal stock number
5	Holding power

The holding power is calculated from the weight and the factors given in HLDFAC.

VARIABLE	DESCRIPTION
NANCR	An array listing the number of anchors of each type in the inventory.
BTYPE	Label for each of two buoy types. Each label is 3 six-character Hollerith words.
BUOTAB	Storage for buoy data for up to two buoy types. The array allows up to six buoys of each type, listed in order of increasing buoyancy. Seven items are given for each buoy:

WORD	CONTENTS
1	Outside diameter
2	Height
3	Weight
4	Nominal buoyancy
5	Maximum Buoyancy
6-7	Hollerith label for federal stock number

VARIABLE	DESCRIPTION
NBUOY	An array listing the number of buoys of each type in the inventory.
HTYPE	Label for each of 4 hawser types. Each label is 3 six-character Hollerith words.
HAWTAB	Storage for hawser data for up to 4 hawser types. The array allows up to 23 sizes for each type. The two items given for each size are the tensile strength and the weight per 100 units of length.
HAWSIZ	A list of the hawser sizes given in increasing order. It is assumed that all four hawser types have the same list of sizes. If no entry is available for a given size then set the strength to zero and the weight to some small, non-zero number.
NHAWS	Set to 23 for each hawser type.
CHAIN	Storage array for chain data. Presumes only one chain type (stud-link chain). The array contains 31 entries for size, strength and weight per unit length.

VARIABLE	DESCRIPTION
NCHN	The number of chain entries (31).
HLDFAC	A list of the holding power factors for the 6 anchor types. This is the number which multiplies the anchor weight to get the holding power in firm sand.

The component data presently listed in the inventories assumes weights, buoyancies and strengths are in units of pounds. Lengths and buoy dimensions are in feet. Hawser and chain sizes are in inches.

It would be possible to alter the contents of the inventories by rewriting the COMPDAT subroutine. The subroutine is called once each time a component check or design selection is made. It is presently set up to avoid re-calculating entries after the first call. The program uses the items in the arrays to search for the appropriate entries. The appropriate values are then selected, scaled without altering the arrays, and used. Minor changes could be made without changing the calling program. More extensive changes or generalizations may require some modifications (not major) in the calling program.

A listing of the present version of COMPDAT and the inventories it contains are presented on the following pages.

C O M P O N E N T   I N V E N T O R Y

ANCHOR TYPE = NAVY STD STOCKLESS

WEIGHT	FED. STOCK NO.	HOLD. POWER (FIRM SAND)
.30000E+04	C2040-516-7758	.21000E+05
.50000E+04	C2040-516-7757	.35000E+05
.60000E+04	C2040-516-7756	.42000E+05
.70000E+04	C2040-516-7755	.49000E+05
.90000E+04	C2040-516-7754	.63000E+05
.10000E+05	C2040-272-2244	.70000E+05
.13000E+05	C2040-272-2245	.91000E+05
.14500E+05	C2040-272-2246	.10150E+06
.18000E+05	C2040-516-7753	.12600E+06
.20000E+05	C2040-272-2247	.14000E+06
.25000E+05	C2040-272-2242	.17500E+06
.30000E+05	C2040-272-2243	.21000E+06
.40000E+05	C2040-277-2423	.28000E+06

ANCHOR TYPE = NAVSHIP(LWT)

WEIGHT	FED. STOCK NO.	HOLD. POWER (FIRM SAND)
.10000E+03	H2040-377-8600	.28374E+04
.15000E+03	H2040-377-8601	.39565E+04
.20000E+03	H2040-377-8602	.50091E+04
.30000E+03	H2040-377-8603	.69848E+04
.50000E+03	H2040-377-8604	.10619E+05
.75000E+03	H2040-377-8605	.14807E+05
.10000E+04	H2040-377-8606	.18746E+05
.15000E+04	H2040-377-8607	.26140E+05
.20000E+04	H2040-377-8608	.33095E+05
.25000E+04	H2040-377-8609	.39740E+05
.30000E+04	H2040-377-8610	.46148E+05
.40000E+04	H2040-377-8611	.58426E+05
.50000E+04	H2040-378-5633	.70157E+05
.60000E+04	H2040-378-5634	.81470E+05
.10000E+05	H2040-377-8612	.12385E+06
.13000E+05	H2040-377-8613	.15358E+06

ANCHOR TYPE = NAVFAC STATO

WEIGHT	FED. STOCK NO.	HOLD. POWER (FIRM SAND)
.20000E+03	2CF2040-800-9659	.40000E+04
.30000E+04	2CF2040-702-7864	.60000E+05
.60000E+04	2CF2040-702-6785	.12000E+06
.90000E+04	2CF2040-702-6786	.18000E+06
.12000E+05	2CF2040-702-6787	.24000E+06
.15000E+05	2CF2040-801-7938	.30000E+06

BUOY DATA

BUOY TYPE = BAR RISER CHAIN

O. D.	HEIGHT	WEIGHT	NOM. BUOYANCY	MAX. BUOYANCY	FED. STOCK NO.
6.53125	4.03125	2200.	3562.	4300.	C2050-223-3657
7.03125	5.03125	2500.	5835.	7518.	C2050-264-4497
9.50000	5.00000	7700.	7420.	10445.	C2050-223-3665
10.50000	6.50000	9600.	14414.	20879.	C2050-223-3662
10.50000	7.50000	10100.	17608.	25921.	C2050-264-4498

STEEL STUD-LINK CHAIN

SIZE	STRENGTH	WEIGHT/LENGTH
.7500	48550.	5.5556
.8750	65280.	7.7778
1.0000	84500.	9.4444
1.1250	106080.	12.2222
1.2500	130070.	15.0000
1.3750	156330.	17.7778
1.5000	185060.	21.1111
1.6250	216030.	24.4444
1.7500	249210.	28.3333
1.8750	284540.	32.7778
2.0000	322000.	36.6667
2.1250	361530.	41.1111
2.2500	403100.	46.6667
2.3750	446660.	51.6667
2.5000	492190.	57.7778
2.6250	539620.	63.3333
2.7500	588930.	70.0000
2.8750	640070.	76.6667
3.0000	693000.	83.3333
3.1250	747680.	91.1111
3.2500	804070.	98.3333
3.3750	862130.	106.1111
3.5000	921810.	114.4444
3.6250	983080.	122.7778
3.7500	1045900.	131.1111
3.8750	1110210.	140.0000
4.0000	1176000.	148.8889
4.1250	1234200.	158.8889
4.2500	1311790.	170.0000
4.3750	1381330.	183.8889
4.5000	1452930.	198.3333

HAWSER DATA

SIZE	Code 1 2-IN-1 NYLON STRENGTH	WEIGHT/100L	Code 2 2-IN-1 POWER BRAID STRENGTH	WEIGHT/100L	Code 3 2-IN-1 STABL BRAID STRENGTH	WEIGHT/100L	Code 4 12 ST. BLUE STREAK STRENGTH	WEIGHT/100L
.5000	8300.	6.50	7500.	5.90	7500.	7.90	6300.	6.40
.7500	18000.	15.00	16000.	13.00	16000.	18.00	13600.	14.00
1.0000	31300.	26.00	28400.	24.00	26400.	32.00	23500.	25.00
1.0625	36500.	31.00	33200.	28.00	33200.	37.00	0.	.10
1.1250	42600.	36.00	38000.	32.00	38000.	43.00	31500.	33.00
1.2500	47700.	41.00	43600.	37.00	43600.	49.00	36000.	38.00
1.3125	54000.	47.00	49000.	42.00	49000.	56.00	40600.	44.00
1.5000	67500.	60.00	61400.	53.00	51400.	71.00	50800.	55.00
1.6250	82600.	74.00	75000.	65.00	75000.	88.00	62200.	68.00
1.7500	99000.	89.00	90000.	80.00	90000.	106.00	74400.	82.80
2.0000	117000.	106.00	106000.	95.00	106000.	125.00	88000.	99.00
2.1250	136000.	124.00	124000.	111.00	124000.	148.00	102000.	115.00
2.2500	156000.	144.00	142000.	129.00	142000.	172.00	117000.	134.00
2.5000	178000.	165.00	162000.	149.00	152000.	197.00	134000.	153.00
2.6250	202000.	188.00	183000.	168.00	153000.	224.00	151000.	175.00
2.7500	226000.	212.00	205000.	190.00	235000.	253.00	170000.	197.00
3.0000	252000.	238.00	223000.	213.00	229000.	284.00	190000.	222.00
3.2500	308000.	294.00	290000.	263.00	280000.	350.00	232000.	274.00
3.6250	369000.	356.00	336000.	318.00	336000.	424.00	278000.	332.00
4.0000	436000.	423.00	396000.	379.00	396000.	504.00	327000.	395.00
4.2500	504000.	497.00	461000.	444.00	451000.	592.00	381000.	463.00
4.6250	586000.	576.00	531000.	515.00	531000.	686.00	439000.	537.00
5.0000	666000.	662.00	606000.	592.00	636000.	788.00	500000.	617.00

APPENDIX D

DESCRIPTION OF THE SHIP MOTION FILE

The data for the motion equations for a ship driven by harmonic waves is provided to the SEADYN/DSSM program through the Ship Motion File. This set of data is assumed to be on a sequential binary file on logical unit 08. This Appendix describes the format of that file. The notations of Reference 4 are used.

The equations of motion for a ship moving in waves on a free surface are assumed to have the following form:

$$\sum_{k=1}^{6} (M_{jk} + A_{jk})\ddot{\eta}_k + B_{jk}\dot{\eta}_k + C_{jk}\eta_k = F_j e^{iW_E t}, \; j = 1, \ldots, 6 \qquad \text{(D-1)}$$

The terms of this equation are assumed to be provided on the Ship Motion File in a non-dimensional form reflecting the effects of the wave length of the surface wave and the relative heading between the wave and the ship.

The relationships between the terms of equation (D-1) and the non-dimensional terms on the file are given below:

$$M_{jk} = M \,.\, L^{n(j,k)} \,.\, GMU(J,K) \qquad \text{(D-2)}$$

Units: $FT^2\ L^{n-1}$

$$A_{jk} = M. \ L^{n(j,k)} \,.\, DA(J,K) \qquad \text{(D-3)}$$

Units: $FT^2\ L^{n-1}$

$$B_{jk} = M \,.\, \sqrt{g/L} \,.\, L^{n(j,k)} \,.\, DB(J,K) \qquad \text{(D-4)}$$

Units: FTL^{n-1}

$$B^*_{44} = M \,.\, \sqrt{g/L} \,.\, L^2 \,.\, B44S\ (I_{RA}) \qquad \text{(D-5)}$$

Units: FTL

$$C_{jk} = M \,.\, g \,.\, L^{n(j,k)-1} \,.\, DC(J,K) \qquad \text{(D-6)}$$

Units: FL^{n-1}

$$F_j = M \cdot g \cdot L^{m(j)-1} \cdot \begin{array}{l} (BOD(J,1) + iBOD(J+3,1)) \; J=1,3,5 \\ (BEV(J,1) + iBEV(J+3,1)) \; J=2,4,6 \end{array} \qquad \text{(D-7)}$$

Units: FL^{m-1}

where:

M = Ship's mass (TMAS)
Units: $FT^2 L^{-1}$

L = Ship's length (ELL)

Units: L

g = gravitational acceleration (GRAV)

Units: LT^{-2}

I_{RA} = the Ith roll angle index

$n(j,k) = m(j) + m(k)$

$m(j) = 0$ for $j \leq 3$

$\quad\quad 1 \quad j > 3$

$i = \sqrt{-1}$

The coefficients are assumed to be linearized for a unit motion amplitude and wave height. The usual units for the Ship Motion File are:

F - long tons (2240 lbs)

L - feet

T - seconds

Angles and angular responses are assumed to be in radians.

In addition to the ship motion coefficients the Ship Motion File provides coefficients for estimating the steady state approximations of the second order, wave induced drift forces. These dimensionless coefficients are used to estimate the drift forces once the magntiudes of the ship responses, η_i, are obtained.

The drift force components are:

Surge

$$\bar{F}_x = M \;.\; g \;.\; \sum_{j=1}^{7} \sum_{k=1}^{7} \frac{\bar{\eta}_j}{L^{1-m(j)}} \; \frac{\bar{\eta}_k}{L^{1-m(k)}} \; TX(J,K) \qquad \text{(D-8)}$$

Units: F

Sway

$$\bar{F}_y = M \;.\; g \;.\; \sum_{j=1}^{7} \sum_{k=1}^{7} \frac{\bar{\eta}_j}{L^{1-m(j)}} \; \frac{\bar{\eta}_k^*}{L^{1-m(k)}} \; TY(J,K) \qquad \text{(D-9)}$$

Units: F

Yaw

$$\bar{M}_z = M \;.\; g \;.\; L \;.\; I_m \; \sum_{j=1}^{7} \sum_{k=1}^{7} \frac{\bar{\eta}_j}{L^{1-m(j)}} \; \frac{\bar{\eta}_k^*}{L^{1-m(k)}} \; TM(J,K)$$

$$\eta_o \; Re \; \sum_{j=1}^{7} \frac{\eta_j}{L^{1-m(j)}} \; TP(J) \qquad \text{(D-10)}$$

Units: FL

where:

η_o = wave amplitude (real number)

$$\bar{\eta}_j = \begin{Bmatrix} \eta_1 \\ \eta_2 \\ \vdots \\ \eta_6 \\ \eta_o \end{Bmatrix} \text{ augmented ship response}$$

$m(j)$ = 0 for j = 1,2,3,7

1 for j = 4,5,6

( )* means complex conjugate

This presumes the wave motion is given by $\eta_o \, e^{iwt}$ where η_o is real and the ship response is $\eta_i \, e^{iwt}$.

The coordinate system presumed for ship's motions and forces is a right-handed cartesian system with its origin at the ship's center of gravity, its x axis positive aft, its y axis positive starboard, and its z axis positive upward. The angular convention for the relative heading between the ship and the waves assumes the following:

Wave Heading	Description
0°	Following seas
90°	Beam seas with waves traveling from port to starboard
180°	Head seas
270°	Beam seas with waves traveling from starboard to port

The differences between the wave heading convention and the ship's coordinates should be noted.

The Ship Motion File is organized in logical records. The specific contents of each record will be described below. There are seven distinct record types. The first two records contain data which is independent of wave heading or wavelength. Record types 3 through 7 are dependent on heading and wavelength and are repeated in a nested loop fashion. The overall form is:

Record 1
Record 2

Loop on Wave Length	Loop on Wave Heading	Record 3 Record 4 Record 5 Record 6 Record 7

The wave headings are assumed to be listed in decreasing order with $+180^{\circ}$ being the largest allowed. The interpolation routines assume the values given for $+180^{\circ}$ will be used for -180°, therefore data for -180° need not be given.

The wave lengths are assumed to be listed in decreasing order (i.e., increasing frequency order).

The individual records of the file are described in terms of the Fortran read/write lists associated with each record.

RECORD 1 NAME 1, NAME 2, NAME 3

Three Hollerith variables providing identifying data.

RECORD 2 (TITO(I), I=1, 12), WORD, WORD 2, WORD 3, ELL, BEAM, DRAFT, TVOL, TMAS, TPST, ZG, CBV, NOB, (FN(I), I=1, NOB), NOH, (HDGI(I), I=1, NOH), NOK, (BAM(I), I=1, NOK), VNY, GRAV, NRV, (RANG(I), I=1, NRV), ((GMU(I,J), J=1, 6), I=1,6), ((DC(I,J), J=1,6), I=1,6)

TITO = Hollerith title consisting of 12 6-character words
WORD = length unit label (6-character Hollerith)
WORD 2 = force unit label (6-character Hollerith)
WORD 3 = moment unit label (6-character Hollerith)
ELL = Ship's length (L)
BEAM = Beam (L)
DRAFT = Draft (L)
TVOL = Ship's volume is obtained from $(ELL/2)^3$. TVOL
TMAS = ship's mass (FS^2L^{-1})
TPST = Longitudinal distance from c.g. to forward most station is obtained from (ELL/2) . TPST
ZG = vertical distance from water line to c.g., (+ up) (L)
CBV = vertical distance from water line to center of buoyancy (+ up) is obtained from ELL . CBV
NOB = number of speeds (SEADYN/DSSM expects only one)
FN(I) = the Froude numbers for each speed
NOH = number of wave headings
HDGI(I) = the wave headings listed in decreasing order starting with 180° and proceeding no further than $-180^{\circ} + \Delta\Theta$
NOK = number of wave lengths
DAM(I) = non-dimensional wave length in decreasing order, λ = ELL . BAM(I)

VNY = fluid viscosity (L^2T)

GRAV = gravitational acceleration (LT^{-2})

NRV = number of roll angles

RANGE(I) = the values of roll angles (radians) listed in increasing order

GMU(I,J) = the non-dimensional mass matrix

DC(I,J) = the non-dimensional hydrostatic restoring matrix

RECORD 3 MM, HDGI(MM), JJ, FN(JJ), LL, BAM(LL)

MM = heading number

JJ = speed number

LL = wave length number

RECORD 4 ((DA(I,J), J=1,6), I=1,6), ((DB(I,J), J=1,6), I=1,6)

DA(I,J) = the non-dimensional added mass matrix for the current combination of heading, speed, and wave length

DB(I,J) = the non-dimensional wave damping matrix

RECORD 5 (BOD(I), BOD(I+3), BEV(I), BEV(I+3), I=1,3)

BOD, BEV = the non-dimensional wave force coefficients.

RECORD 6 (B44S(I), I=1, NRV)

B44S(I) = the non-linear roll damping terms which are added to the damping matrix depending on the size of the roll angle (non-dimensional).

RECORD 7 ((TX(I,J), I=1,7), J=1,7), ((TY(I,J), I=1,7), J=1,7), ((TM(I,J), I=1,7), J=1,7), (TP(I), I=1,7)

The non-dimensional drift force coefficients.

APPENDIX E

LINEARIZED FLUID DAMPING ON CABLE ELEMENTS

An approximate form of the fluid damping effects are developed in this Appendix. To obtain this approximation it is assumed that flow field induced drag is accounted for separately in a static analysis and only the dynamic response of the cable element contributes to the drag damping. This assumption neglects a cross term involving the local flow field velocity and the element velocity which arises from squaring the relative velocity [2] . A one dimensional example will clarify the matter. Given a body moving parallel to the flow in a uniform stream. If the stream velocity is V_s and the velocity of the body is V_B, then the drag loading on the body is proportional to

$$(V_s - V_B)^2 = V_s^2 - 2V_sV_B + V_B^2 \tag{E-1}$$

The approximation introduced here amounts to saying that V_s is applied to the system to obtain a static reference position of the body and V_B represents the velocity of oscillation about that state. The drag contributions from V_B are linearized and the cross term $-2V_sV_B$ is neglected.

Assume an element in its local coordinate system. Further assume that the drag force per unit length has the following linear form:

$$\left\{ \xi \right\} = \left\{ \begin{matrix} 0 \\ C_e\dot{V} \\ C_e\dot{W} \end{matrix} \right\} \tag{E-2}$$

where C_e is a equivalent linearized damping coefficient

$\dot{V}$, $\dot{W}$ components of the element velocity in two orthogonal directions normal to the element.

Using the finite element approximation with a linear shape function leads to

$$\left\{ f \right\} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & C_e & 0 \\ 0 & 0 & C_e \end{bmatrix} \cdot \begin{bmatrix} N \end{bmatrix} \left\{ \dot{q} \right\} \tag{E-3}$$

where N is the shape function matrix

$\{\dot{q}\}$ are the nodal velocities

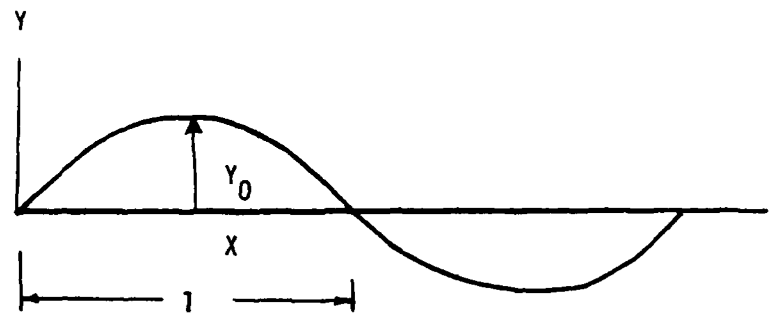
The nodal damping forces for the element are then given by:

$$\{f_D\} = \int_0^L \begin{bmatrix} N \end{bmatrix}^T \begin{bmatrix} 0 & 0 & 0 \\ 0 & C_e & 0 \\ 0 & 0 & C_e \end{bmatrix} \begin{bmatrix} N \end{bmatrix} dx \ \{\dot{q}\} \tag{E-4}$$

Carrying out the integrations for linear shape functions yields:

$$\{f_D\} = \frac{C_e L}{3} \left[\begin{array}{ccc|ccc} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & \frac{1}{2} & 0 \\ 0 & 0 & 1 & 0 & 0 & \frac{1}{2} \\ \hline 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & 0 & 1 & 0 \\ 0 & 0 & \frac{1}{2} & 0 & 0 & 1 \end{array}\right] \{\dot{q}\} \tag{E-5}$$

The definition of the element damping matrix will be complete once an expression for C_e is obtained. This expression can be obtained by considering a segment of cable oscillating harmonically in a transverse mode in a fluid. Assuming the deflected shape is closely approximated by a sine curve facilitiates the development.



$$Y = Y_0 \text{ Sin } wt \sin \frac{\pi X}{l} \qquad \text{(E-6)}$$

$$\dot{Y} = Y_0 \, w \text{ Cos } wt \text{ Sin } \frac{\pi X}{l} \qquad \text{(E-7)}$$

The normal drag per unit length is

$$f = \tfrac{1}{2} \rho_f \, C_N \, d \, (\dot{Y})^2 \qquad \text{(E-8)}$$

The work done in one cycle over the length l is

$$W = \oint \int_0^l fdxdy = 2 \int_{-\frac{\pi}{2w}}^{\frac{\pi}{2w}} \int_0^l fdx\dot{y}dt$$

$$= \rho_f \, C_{Nd} \int_{-\frac{\pi}{2w}}^{\frac{\pi}{2w}} \int_0^l (\dot{y})^3 \, dxdt \qquad \text{(E-9)}$$

An equivalent linear form for the normal drag force per unit length can be written:

$$f_e = C_e \dot{y} \qquad \text{(E-10)}$$

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The equivalent work term is:

$$W_e = \oint \int_0^1 C_e \dot{y}\,dxdt = 2C_e \int_{-\frac{\pi}{2w}}^{\frac{\pi}{2w}} \int_0^1 (\dot{y})^2\,dxdt \qquad \text{(E-11)}$$

Requiring that the linearized term must dissipate the same energy per cycle as the non-linear term yields

$$C_e = \frac{\frac{1}{2}\rho_f C_N d \int_{-\frac{\pi}{2w}}^{\frac{\pi}{2w}} \int_0^1 (\dot{y})^3\,dxdt}{\int_{-\frac{\pi}{2w}}^{\frac{\pi}{2w}} \int_0^1 (\dot{y})^2\,dxdt} \qquad \text{(E-12)}$$

Substituting from equation (E-7) and carrying out the integration yields;

$$C_e = \frac{32}{9\pi^2}\,\rho_f\,C_N d w y_0 \qquad \text{(E-13)}$$

These results are applied in the computer program by assuming $\dot{y}_0 = 0.01$ for calculating C_e when starting from a static state and selecting $\dot{y}_0$ to be the largest of the normal components of the nodal velocities on each element on subsequent iterations. A minimum of two iterations are required.

ADDENDUM TO REPORT DSSM-2
USER'S MANUAL FOR SEADYN/DSSM

28 December 1976

The equations for the added mass and damping coefficients for mooring buoys which are given in equations (2-46) through (2-49) on page 22 proved to be cumbersome for programming. A polynomial curve-fitting of the original curves given by Kim[12] was used in the program. The polynomial coefficients are given below.

FUNCTION	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7
M_x	1.0620	-0.4090	5.3299	-10.0143	7.6387	-2.9089	0.5509	-0.0414
M_z	1.7945	1.3362	-10.9227	18.0521	-13.8920	5.5725	-1.1249	0.0902
N_x	0.	-1.5252	7.2144	-8.6447	5.0535	-1.6218	0.2750	-0.0192
N_z	0.	4.3747	-9.8378	10.7232	-6.6657	2.3676	-0.4439	0.0339

The equation form is $F = \sum_{i=0}^{7} a_i (a')^i$

This page added
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END